SEP 6 1913
PRINCETON, N. J.

Technical Paper 49 Petroleum Technology 10

For 2d ed. see next paper.

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE FLASH POINT OF OILS

METHODS AND APPARATUS FOR ITS DETERMINATION

BY

IRVING C. ALLEN AND A. S. CROSSFIELD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1913

First edition. May, 1913.

CONTENTS.

Page.
Introduction 5
The flash point 5
The fire hazard 5
Attempts to determine flash points 6
  Attempts in Great Britain 6
  Attempts in the United States 7
  Principal testers used 7
  Comparison of the principal testers 7
Classification of testers 8
  Open-cup testers with water bath 8
  Open-cup testers with air baths and sand baths 8
  Semiclosed testers 9
  Closed testers 9
  Open testers with saturated vapors 9
  Closed testers with saturated vapor 10
  Closed vapor-pressure testers 10
Distillation tests 11
Factors to be considered in determining the flash point 11
  Manner of making tests 11
  Effect of barometric conditions 11
  Features of oil cup 11
  Features of thermometer 13
    Size of bulb 13
    Depth of immersion 13
    Correction for exposed portion of stem 13
  Rate of heating 13
  Effect of prolonged heating or cooling 14
  Importance of stirring the oil 14
  Size of test flame 14
  Distance of test flame above oil 14
  Comparison of gas, oil, and electric test flames 15
  Effect of duration of exposure of the test flame 15
  Effect of room temperature 15
  Burning point 15
  Effect of water 16
  Removal of water prior to testing 16
  Effect of the personality of the operator 17
Relation of flash point to density 17
Testers recommended by foreign governments and by the Government of the United States 17

Page.
Testing the flash point of lamp oils with the Abel-Pensky tester 18
  Selection of the workroom 18
  Selection and care of the sample 18
  Reading the barometer 18
  Preliminary tests 19
  Filling and warming the bath 19
  Filling and adjusting the tester 19
  Making the test 19
The Pensky-Martens tester 20
Burning point 20
Substitute or secondary testers 20
  The open-cup test 23
  The test-tube tester 23
Bibliography 25

ILLUSTRATIONS.

FIGURE 1. Abel-Pensky flash tester, Bureau of Mines model 21
2. Pensky-Martens flash tester, Bureau of Mines model 22

THE FLASH POINT OF OILS; METHODS AND APPARATUS FOR ITS DETERMINATION.

By Irving C. Allen and A. S. Crossfield.

INTRODUCTION.

In the handling of lamp oils, particularly in mines and in buildings where open lights are used, it is important that a relatively safe oil; that is, one with a high flash point, be employed. Equally important is the determination of the inflammability of all oils in common use. This paper, which is published by the Bureau of Mines in the interest of greater safety at mining and metallurgical plants, does not aim to establish definite flash points for oils but describes the instruments and methods of testing that can be used as a basis on which to establish such flash points. In connection with the discussion of the subject of this paper effort has been made to present a complete bibliography. The numbers in parentheses in the text refer to the books or articles as numbered in the bibliography.

THE FLASH POINT.[a]

In the various methods used for determining the flash point of an oil the temperature at which its vapor flashes is not a definite factor but is dependent on a number of physical and chemical conditions not under the control of the operator. It is not an indication of the value of an oil for any particular purpose. It is an indication only of the temperature at which the oil gives off vapors in such proportions that they form an inflammable mixture with the air. If exposed to an electric light or a flame the mixture will ignite and the flame extend throughout the mixture; that is, an explosive mixture of vapor and air is formed.

THE FIRE HAZARD.

The flash point, although probably the most important factor, will not by itself determine the fire hazard of any substance. The fire hazard of a substance is also affected by the volatility, the boiling point, the vapor pressure, the vapor density, the diffusibility and tendency of the vapors to travel and their explosive limits in air, its tendency to chemical change, the quantity of heat liberated per unit of time and unit of volume, the temperature of the flame, the corrosive action and toxic properties of the substance and of its products of combustion, its behavior toward water both before and after ignition, and the tendency of the substance to leak.

---

[a] See 1 of bibliography, p. 25.

A requirement that an oil have the highest practicable flash point, tending thereby to reduce the fire hazard to a minimum, is praiseworthy and humane. To require too high a flash point may impair the burning qualities of a lamp oil and also work a hardship on the refiner. However, the immediate profits of the refiner should be deemed less important than the safety of the user and the protection of the public against possible loss of life and of property by fire (2).

The fire hazard of lubricating oils is of importance when the lubricants are used in rapidly running machinery, as in spinning mills, wood mills, etc., or are used in factories containing combustibles and in compressors for air, ammonia, or other gases (3).

Particular attention should always be given to the handling, storage, and inspection of all inflammable liquids (6–9).

ATTEMPTS TO DETERMINE FLASH POINTS.

In the endeavor to ascertain the temperature at which an oil becomes dangerous many workers have experimented through a long series of years with numerous instruments and methods of testing, have developed many patterns of apparatus, and have ascertained some important facts regarding the determination of fire hazards.

The ordinances in the several States of the United States regarding the fire hazards of petroleum products, based solely on the flash points of the products, have been formulated independently of one another and seem to have little in common. The testers used are not comparable with each other as they embody different theoretical considerations, vary in dimensions and in construction (10,11), and yield results that differ widely. This utter lack of uniformity works a hardship on the refiner and confuses the public.

ATTEMPTS IN GREAT BRITAIN.

As early as 1862 (12) the Government of Great Britain realized the importance of obtaining an instrument and a method of testing that would show the tendency of an oil to ignite, and in 1868 Sir Frederick Abel, Dr. Letheby, and Dr. J. Attfield were authorized to investigate the general matter of flash tests (13). This committee presented for consideration, but without definite specifications, the ordinary open-

Digitized by Google Original from PRINCETON UNIVERSITY

cup tester, which, however, because of its inaccuracies, did not meet with general acceptance. The subject continued to occupy the attention of Parliament from time to time until 1875, when Abel proposed an instrument that was almost identical with the present Abel-Pensky tester and has since then been considered the official tester of that Government (14).

ATTEMPTS IN THE UNITED STATES.

About this time—that is, between 1860 and 1880—the consideration of flash-point determination occupied the attention of the American public. Testers of various patterns were suggested and have been used independently by the numerous men interested, and many different testers are in use to-day in spite of their inaccuracies and the widely varying results obtained by them (15). C. D. Chamberlain, secretary and counselor general of the National Petroleum Association, stated in 1910 (16):

> Thirty-four of our forty-six States have laws providing for the inspection of petroleum and its products, and yet no two States have a law in common. This in itself forbids economy in manufacture; if a definite oil has to be manufactured to suit the requirements of each State there must necessarily be waste.

The situation has not materially changed since that time.

PRINCIPAL TESTERS USED.

The testers used in the United States are of many kinds and give different results. The seven best known testers are the Tagliabue open tester (17), the Tagliabue closed tester (18), the Elliot or New York State tester (19), the Foster tester (20), the Cleveland tester, the Abel-Pensky tester (21), and the Pensky-Martens tester (22). In addition an ordinary small open glass beaker or porcelain evaporating dish warmed over a flame or on a water or sand bath is still much used.

COMPARISON OF THE PRINCIPAL TESTERS.

The open-cup testers, as the Cleveland and the Tagliabue open-cup, with lamp oils, give results about 5° C. above the flash point, and in the case of heavy lubricating oils the flash point may be 25° C. higher than the flash point determined with the Abel-Pensky or the Pensky-Martens testers. The Foster tester reads some 3° C. higher than the Tagliabue "closed tester." The Tagliabue "closed tester" reads some 8° C. higher than the Elliot tester, and 2 to 3° C. higher than the Abel-Pensky tester (23). For further comparisons see references 24 to 26 in the bibliography.

CLASSIFICATION OF TESTERS.

Testers may be grouped into six classes, namely: (1) Open-cup testers, (2) semiclosed testers, (3) closed testers, (4) open testers with saturated vapors, (5) vapor-pressure testers, and (6) distilling testers.

OPEN-CUP TESTERS WITH WATER BATH.

Albrecht (27), S. Aisinmann (27), J. Allen (28), Arnaboldi (29), J. Attfield (30), C. F. Chandler (31, 32), the inventor of the Cleveland tester, the Danes (33), Ehrenberg (34), C. Engler (35), C. Engler and R. Haass (36), H. Engler (37), Ernecke and Hannemann (38), E. Granier (39), H. Höfer (40), Hutton (41), the inventor of the Indiana State tester (42), E. Jacobson (43), Kyll (44), Lenoir and Foster (45), the inventor of the Minnesota State tester (46), Möser (47), G. Saybolt (48), Squires (49), Tagliabue (17), R. Vette (50), H. N. Warren (51), V. Weise (52), and others experimented with a simple open cup about 5 centimeters in diameter and 7 centimeters in depth. The cup was half filled with the oil to be tested, and warmed on a water bath. From time to time a small lighted taper was exposed momentarily to the oil vapors. When the oil vapors ignited and showed a flash of flame the temperature of the oil was ascertained by a thermometer, the bulb of which had been previously immersed in the oil.

OPEN-CUP TESTERS WITH AIR BATHS AND SAND BATHS.

F. A. Courtois (53) worked with lamp oils in a manner similar to that used by other investigators, but warmed his oil cup on an air bath, whereas for lubricating oils R. Kissling (54), A. Künkler (55), J. Marcusson (56, 57), E. Stoeber (58), and Truemann (59), heated the oil in a small open porcelain dish or crucible fixed in a sand bath, and P. H. Walker (60) used a nickel crucible heated on an asbestos ring. W. Herbig (61) improved this open tester by covering the dish with a fire-clay tile provided with a small hole through which to introduce the test flame.

In all of the open-cup testers the most volatile and inflammable of the vapors escape first, but not in sufficient quantity to be readily ignited. When the temperature reaches the point at which the vapors are given off in sufficient quantity for ignition, the temperature of the oil has risen above its lowest flash point or that temperature at which the accumulated vapors would have been inflammable in a closed vessel, the condition most closely resembling that of oil in the reservoir of a lamp or in an oil tank. The temperature of the oil in the open cup, therefore, is not the true flash point, but is from 5° to 25° C. too high (27). Also the vapors rising freely from the surface of the oil in an open cup, even in a carefully sheltered room, are exposed to air currents and drafts which seriously interfere with the test; furthermore, the operator may breathe on the surface of the oil, unless he take most scrupulous care to avoid doing so, and thus cause other variations in the accumulation of vapors, so that the apparent flash point obtained will be too high. The combined errors may cause a variation of from 1° to 12° C. in the determination of the flash point, depending on the substance tested (24). Moreover, the ignition flame must be applied in a precise manner to insure uniform results, and such application is not practicable in any of these open-cup testers.

SEMICLOSED TESTERS.

Various investigators improved the open-cup tester by adding a cover with a small opening through which the test flame was applied to the vapors or through which the vapors were allowed to escape past the burning taper. Among these investigators were O. Braun (62), C. F. Chandler (63), A. H. Elliot (19), C. Engler (64, 65), Foster (20), Heumann (66), Kuckla (67), Luchaire (68), Mann (69), Millspaugh (70), E. Parrish (71), the deviser of the Phlog-elaio-metre tester (72), J. Skalweit (73), Tagliabue (18), the deviser of the Wisconsin tester (74), and others (75).

CLOSED TESTERS.

Although the semiclosed testers gave more uniform results, considerable variations were noted in determinations made by careful workers, and F. Abel (21, 76), Pensky-Martens (22), A. Bernstein (77), O. Braun (78), C. Engler (35, 79, 80), A. Gawalowski (81), Granier (82), J. Gray (83), J. A. Harker (84), D. Holde (85, 86), E. Jacobsen (87), T. W. Keates (88), Künkler (89), Letheby (90), Pease (91), G. Saybolt (92, 93), Schmitz (94), Sintenis (95), Vette (96), R. Weber (97), and H. F. Wiebe (98–100), worked with closed testers fitted with a small slide that opened and closed a small aperture through which the test flame could be applied at any desired instant.

OPEN TESTERS WITH SATURATED VAPORS.

Other workers, as F. F. Beilstein (101), L. Liebermann (102), A. Reythien and H. Hempel (103), and J. T. Stoddard (104, 105), determined the tendency of an oil to generate vapors by bubbling a current of air through the oil warmed on a water bath, allowing the mixture of oil vapor and air to pass a lighted taper at the opening of the oil cup and noting the temperature at which ignition occurred.

Although these workers claimed satisfactory results, the authors have found that results with this type of tester can be made to vary

Original from PRINCETON UNIVERSITY

widely by changing the volume of the air current. With a slow stream of small air bubbles passing at the rate of about 0.1 c. c. per second into a 100 c. c. test tube containing 20 c. c. of oil, immersed in a well-stirred water bath, and with all precautions taken to correct the temperature readings, an oil that flashed in an Abel-Pensky tester at 44° C. flashed at a temperature above 50° C. On increasing the air current to a quantity sufficient to give a froth about 1 centimeter deep on the oil a flash point below 30° C. was observed. Because of this wide range in the results obtained, depending alone on the quantity of air used for agitation and combustion, and as any particular quantity of air must of necessity be fixed arbitrarily, it is believed that this method for accurate testing is not reliable.

CLOSED TESTERS WITH SATURATED VAPOR.

The method of Beilstein and others for generating the vapors was improved by R. Haass (106, 107), H. Hörler (108), and V. Meyer (109, 110), who warmed a definite quantity of oil and air contained in a closed vessel on a water bath to any temperature desired. The vessel was then agitated by vigorous shaking and replaced in the water bath. The froth and mist formed were allowed to settle until the oil had come to the temperature of the bath. The vessel was then removed, the vapors exposed to a flame or an electric spark, and the flash determined. This method insures the space above the oil being saturated with oil vapor, a condition not true of any other tester, and not necessarily true of the reservoir of a lamp.

The test, however, determines only whether the oil will or will not flash at a given temperature, and is valuable for this purpose only. But to determine the flash point of an oil requires repeated tests, which with this apparatus are time-consuming and hence not practicable. The flash points determined with this apparatus are some 9° C. (106) lower than those determined with the Abel-Pensky and Pensky-Martens testers.

CLOSED VAPOR-PRESSURE TESTERS.

In efforts to determine under what conditions oils become dangerous, K. W. Charitschkoff (111), Geissler (112), Meusel (113), Salleron and Urbain (114, 115), and P. H. Vanderweyder (116) endeavored to establish definite relations between the vapor pressures developed by oils contained in closed vessels and their fire hazard. Their efforts were unsuccessful as the fire hazard, though affected by the vapor pressure, depends on other physical and chemical factors as well (see pp. 5 and 6).

Original from PRINCETON UNIVERSITY

DISTILLATION TESTS.

D'A. de Barran (117), F. P. Beilstein (118), and T. Rosenbladt (119) endeavored, also without success, to establish a definite relation between the fire hazard and the quantity of vapors distilled between given temperatures. P. Dvorkovitz (120) maintains that the distillation test is the best criterion for the determination of the fire hazard of an oil, and states that a good safe oil can be obtained by allowing the finished refined oil to contain a quantity of light oils, of which not more than 10 per cent should distill below 150° C., and not more than 10 per cent should be left as residue after distillation at 300° C.

FACTORS TO BE CONSIDERED IN DETERMINING THE FLASH POINT.

The important points to be considered in the construction and manipulation of an instrument to determine the flash point of an oil may be stated as follows (84, 121):

MANNER OF MAKING TESTS.

Tests should always be repeated and always with fresh samples of oil. The conditions under which the test vapors are generated should be as like as possible to the conditions found in practice. The quantity of oil should be such that no change in composition takes place because of the generation and the consequent loss of the vapors or the lighter fractions from the body of the oil (35, 36, 122).

EFFECT OF BAROMETRIC CONDITIONS.

Barometric pressure has a decided effect on the flash point. A rise of 1 mm. in the barometer raises the flash point, according to different workers, by 0.03000° C. (123), 0.0444° C., 0.0360° C. (124), 0.0355° C. (84), or 0.0444° C. (121), an average of 0.0381° C. A sudden change of barometric pressure, however, causes only a slow change in the flash point (125), because time is an important factor in the evolution of vapors from an oil. The flash point finally observed should be corrected for barometric pressure, applying the proper correction, as given in Table 2.

FEATURES OF OIL CUP.

The shape and size of the oil cup are important. As regards the size of the cup, the greater the surface of oil exposed the more rapid will be the evolution of the light and inflammable vapors at any given temperature, and consequently the lower will be the flash point (76).

The thickness of metal in the cup has significance. A heavy cup and cover will require more heat to warm them, which will lengthen the time of the test. The cup and cover of the German Abel-Pensky tester weighs about 143 grams, whereas that of the British Abel tester weighs about 76 grams. The German Abel-Pensky tester therefore gives a slightly retarded—that is, higher—result than the British Abel tester (10).

The distance of the surface of the oil below the rim of the cup should be definite and always the same. The test should always be made when the oil surface is on the mark and not above it (126). The usual practice is to fill the cup with cold oil to the mark in preparing for the test, and to disregard the expansion of the oil during the subsequent warming.

A projecting point should be used as the mark for filling, as in the Abel-Pensky tester, and not a line, as in the Pensky-Martens tester. The surface of the oil can be read with reflected light at a point projecting 1 cm. from the side of the cup more accurately than at a line on the side of the cup, because the meniscus formed by the oil surface at the side of the cup will distort the reflected image and in obscure light will render precise reading difficult. Filling the cup 2 mm. above the mark in a Pensky-Martens tester may result in depressing the flash point by 2.5° C. with an oil that flashes at 150° C. (27), and as much as 7.5° C. with an oil that flashes at 300° C. A variation in filling of 6 mm. in a Pensky-Martens tester, according to D. Holde (127), makes a difference of 1 to 1.5° C. in the flash point. A. Martens states that an initial filling of 20 c. c. below the mark raises the flash point 1 to 2.5° C. (128), and a filling of 20 c. c. above the mark lowers the flash point 1 to 1.5° C.

The authors found that during a test a particular lamp oil, heated from room temperature (23° C.) to its flash point (46° C.), expanded a vertical distance of 0.5 mm., or 0.022 mm. per 1° C. A lubricating oil, heated from room temperature to its flash point (205° C.), expanded a vertical distance of 2.2 mm., or 0.012 mm. per 1° C. It is important, therefore, that the cup be always filled exactly to a definite point and that it be kept filled to this point during the entire time of the test. The testers used by the Bureau of Mines have been fitted with small overflow tubes as shown at *d*, in figures 1 and 2.

The dimensions of the air space between the cup and the bath are important. The greater the distance the slower will be the rise in temperature, because the slower will be the transmission of heat from the bath to the oil.

The cup should be protected by the bath even to its upper rim, because it is as essential to control the temperature of the vapors as to control that of the oil itself, for the inflammability of the air-vapor mixture is affected by its temperature and this temperature should be the same as that of the oil.

FEATURES OF THERMOMETER.

SIZE OF BULB.

The size of the thermometer bulb is of importance. Differences in dimensions may cause variations in thermometer readings of 0.5° C. (10). The official thermometer used in the British Abel tester gives a flash point 0.14° C. higher than does the thermometer of the German Abel-Pensky tester, principally because of the difference in the size of the thermometer bulbs.

DEPTH OF IMMERSION.

Variations in the depth of immersion of the thermometer bulb are important. An elevation of 2.5 mm. in the depth of the bulb depresses the flash point by 0.32° C. (84). With the bulb immersed to 38 mm. below the surface in an unstirred cup, F. C. Calvert (129) found the flash point of a certain oil to be 34.4° C., whereas with the bulb immersed 7 mm. the flash point was 36.7° C. The difference would have been inappreciable if the oil had been well stirred.

CORRECTION FOR EXPOSED PORTION OF STEM.

F. Mayer (130) found that the correction for the exposed portion of the stem of a thermometer which read to 500° C. and was from 265 to 300 mm. long might be as much as 3.3° C. at 150° C., 4.4° C. at 175° C., 5.8° C. at 200° C., 7.3° C. at 225° C., 9.0° C. at 250° C., 10.7° C. at 275° C., 12.6 ° C. at 300° C., 14.7° C. at 325° C., and 16.8° C. at 350° C. To estimate this error for any given thermometer he developed the following formula: $C=(t-tm)\ lf\ (500\ l)\ 0.00018$, in which C = correction in degrees centigrade, t = temperature of the oil, tm = temperature of the middle of the exposed thermometer thread, lf = length in millimeters of the exposed thermometer thread, l = length in millimeters of the scale of the thermometer, and 0.00018 = cubical coefficient of expansion of mercury.

RATE OF HEATING.

The heating should be slow and regular so that the vapors are evolved just fast enough to maintain equilibrium between the liquid and gaseous phases at a slowly increasing temperature (84, 131). The rate of heating should be between 2° and 3° C. per minute (103), as this rate will insure good equilibrium between the two phases.

The heating should begin at least 10° C. below the flash point, as determined by a preliminary test, in order to give time for equilibrium to be established before the flash point is reached. F. C. Calvert (129) found the flash point of a particular oil to be 34.4° C. when the oil was heated from room temperature to the flash point in 15 minutes, 36.7° C. when the oil was heated to the flash point in 20 minutes, and 39.4° C. when this heating took 30 minutes. He found that if the testing was begun at 7° C. below the flash point, instead of at 10° as stated above, the flash point was raised about 1° C.

EFFECT OF PROLONGED HEATING OR COOLING.

Heating of the oil for a number of minutes prior to testing causes a lowering of the flash point because of the loss of the lightest vapors (125).

On the other hand, cooling of the oil for a number of minutes just prior to testing lowers the flash point because of the condensation and accumulation of these light vapors (132), but if the slide of the tester be left open for some minutes just prior to testing, the cooling has less effect.

IMPORTANCE OF STIRRING THE OIL.

The differences of temperature at different points within the oil in the ordinary unstirred cup may be as much as 3° to 5° C. (84). The oil is hottest along the bottom and sides of the cup. The heated oil rises to the surface along the sides, then flows toward and down the center. It may be 2° to 3° C. hotter than the vapors above it. Therefore the oil and vapors must be thoroughly stirred during the test. For this reason the Abel-Pensky tester for lamp oils that is used by the Bureau of Mines is provided with a stirrer (*e*, fig. 1) similar to that used in the Pensky-Martens tester for lubricating oils.

SIZE OF TEST FLAME.

The size of the test flame is important. A test flame the size of the ivory bead on the cover of the Abel-Pensky tester burns about 0.1 cubic foot of coal gas per hour. A test flame of half this size raises the flash point 1° C., and a test flame of one and a half times this size lowers the flash point 0.5° C. A variation of 20 per cent in the size of the flame causes an inverse variation of 0.3° C. in the flash point (84).

DISTANCE OF TEST FLAME ABOVE OIL.

The distance of the test flame above the oil surface is important. The test flame should be at a definite and constant distance above the surface of the oil, as the distance affects the temperature of the bath, the vapors, and the oil. The farther the test flame is from the surface of the oil, the later the flash and the higher the flash point determined. The test flame should not be brought too near to the oil nor should the exposure be too long, for local heating will result and will cause an error in the reading.

Original from PRINCETON UNIVERSITY

COMPARISON OF GAS, OIL, AND ELECTRIC TEST FLAMES.

A coal-gas test flame gives a flash point 0.3° C. lower than does an oil test flame. An electric test spark gives a variable but usually a lower result than does a gas flame. Because it is not possible to control the intensity and duration of the electric spark and because variations in the intensity and duration of the spark give variable results, the electric test spark should not be used in an official instrument.

EFFECT OF DURATION OF EXPOSURE OF THE TEST FLAME.

The duration of the exposure of the oil vapors to the test flame is important. Frequent opening of the aperture in order to expose the test flame permits frequent escape of the vapors and consequently retards flashing and raises the flash point. Exposing the test flame at each 0.5° C. rise in temperature, as recommended with the German Abel-Pensky tester, gives a flash point 0.14° C. higher than that obtained by exposing the flame at each 1° F. rise in temperature, as is recommended with the British Abel tester (84).

The testing or exposure of the test flame should begin at least 5° C. below the true flash point after correction is made for barometric pressure, as described on page 18.

EFFECT OF ROOM TEMPERATURE.

Allowing the oil to stand for a number of hours in a warm room materially lowers the flash point. Abel (133) found that a lamp oil which ordinarily flashed at 22.8° C. flashed at 18.9° C. when the laboratory was at a tropical temperature (30° C. to 40° C.). In a hot climate or on a hot day the collected vapors should be removed with an aspirator, or one should gently blow over the surface of the cup before putting on the cover in order to obtain results comparable with those obtained with the same oil in a temperate climate or on a cool day. This procedure, however, is not entirely satisfactory, as results obtained by different operators are not uniform. A more satisfactory way is to begin the testing at a temperature some 10° C. below that required in a temperate climate in order to remove the accumulated vapors. This procedure causes the loss of some of the lighter constituents, but such loss is unavoidable, particularly in tropical climates or on hot days or after the oil has stood for a number of hours in a warm room. Concordant results can be obtained in this way.

BURNING POINT.

The legally established flash point for an oil to be used in the Tropics should be somewhat lower than that for the same oil for similar use in a temperate climate.

The burning point, or that temperature at which the oil ignites and continues to burn in an open cup, is of significance. If the oil is a normal refined fraction of petroleum the burning point will be 2° to 11° C. higher than the flash point (134). The difference will be considerably greater, however, if the oil be a mixture of a light and a heavy oil. In the case of a refined oil, however, the higher the flash point the smaller will be this difference (135).

EFFECT OF WATER.

The presence of small proportions of water in heavy oils make the determination of their flash points uncertain, and 1 per cent will prevent flashing entirely (138, 139), or at least will delay the flash until after the water has been distilled from the oil. Matuschek (140) found that 0.1 gram of water in the cup of oil raised the flash point 1° to 2° C. and 0.7 gram of water raised the flash point about 9° C.

Water also causes frothing of the oil. If an oil that flashes above 80° C. contains 0.2 per cent of water, only the approximate flash can be obtained, and then only in an open-cup tester with cautious heating and close attention to prevent boiling over.

REMOVAL OF WATER PRIOR TO TESTING.

Finely divided water in mineral oils is difficult to remove by settling or by heating without causing injury to the oil. Warming in any way or distilling to remove the water seriously lowers the flash point and should be avoided; diluting with a lighter solvent introduces a low-flashing oil that will entirely mask the flash point of the oil being tested. The water is best removed by treatment in an electric separator (141). A convenient method of reducing the water content of an emulsified oil has been developed by F. G. Cottrell, J. B. Speed, and A. C. Wright. The method is admirably adapted to reducing the water content on a large scale. A convenient apparatus for the laboratory may be made as follows:

A glass tube, about 5 cm. in diameter, 30 cm. long, and open at the top, is drawn out at its lower end and fitted with a glass cock. On the inner surface of the tube is fitted a copper-gauze cylinder, extending from the top to 5 cm. from the bottom. Between the gauze and the tube is placed a single wrapping of wet cheesecloth or very thin muslin. The tube, held in a vertical position, has centered within it a heavy copper wire or rod, extending from the top to 5 cm. from the bottom. The copper wire and the copper-gauze cylinder are connected, by means of leads and a switch, directly to the terminals of a high-potential (2,200-volt) step-up transformer.

The tube is filled with the emulsified oil to be examined, and the circuit is closed. The high-tension current breaks down the emulsion, the water is drawn to the wet-cloth surface, trickles down the cheesecloth, and settles in the lower end of the tube, whence it can be drawn off. With oils containing considerable water, the current must be broken at short intervals to prevent overheating of the oil. With all oils, frequent breaking of the current is advisable.

This process readily reduces the water content of an emulsion, with little heating, to a very small proportion and is admirably adapted to reducing the water content of emulsions when heating is objectionable.

EFFECT OF THE PERSONALITY OF THE OPERATOR.

In general testing, so far as is possible, the effect of the personality of the operator should be eliminated and the manipulation of the tester made entirely mechanical and automatic (142). The most accurate tester and the tester that most nearly reproduces actual working conditions should be adopted for official tests.

RELATION OF FLASH POINT TO DENSITY.

There is no definite relation between the flash point and the density of an oil (136, 137) as a very small proportion of light oil, not enough appreciably to affect the density, will materially lower the flash point.

TESTERS RECOMMENDED BY FOREIGN GOVERNMENTS AND BY THE GOVERNMENT OF THE UNITED STATES.

The testers that most nearly meet all the conditions that have been described are the closed Abel-Pensky tester, with stirrer, overflow cup, water bath or oil bath, and mechanical exposure of the test flame for exactly one second, fitted with standardized thermometers for oils flashing up to 60° C. (143); the same tester with a bath of cylinder oil having a flash point of about 250° C. for oils flashing between 60° C. and 150° C.; and the Pensky-Martens tester, with air bath, for oils flashing above 150° C.

The general adoption of these two testers, of like dimensions and, excepting their baths, of like construction, in the United States for all interstate and foreign trade seems advisable, because they are already well known in the United States and are the recognized official instruments in Austria-Hungary, Belgium, Denmark, France, Germany, Great Britain, Holland, Italy, Japan, Norway, Roumania, Russia, and Sweden.

The construction and dimensions of the Abel-Pensky and Pensky-Martens testers are shown in figures 1 and 2, and their manner of manipulation is described on the following pages.

TESTING THE FLASH POINT OF LAMP OILS WITH THE ABEL-PENSKY TESTER.

SELECTION OF THE WORKROOM.

The selection of a suitable workroom is very important. In testing lamp oils it is desirable to carry on the tests in a room with a temperature ranging from 18° to 20° C., and it is essential that the tester used be well protected from all interfering air currents. The illumination of the room should be not too bright, as the test flame and the flash are better observed in a dim light.

SELECTION AND CARE OF THE SAMPLE.

The proper selection and care of the sample are essential. In the selection of a sample for testing one must always be sure that the sample truly represents the oil to be tested. The oil should be thoroughly mixed or the sample should be taken by the aid of a sampling tube from points symmetrically distributed throughout the body of the oil (144). The sample should then be kept hermetically sealed or at least kept in a well-closed vessel in a cool place until ready for use. The sample should stand undisturbed in the workroom for such a time immediately before testing that its temperature becomes practically that of the room.

READING THE BAROMETER.

The reading of the barometer and deciding at what particular temperature the testing should begin are important. Before beginning the test the barometer should be read to the nearest whole millimeter, and then by consulting Table 1 the particular temperature should be ascertained at which the slide should be first opened to expose the test flame. At the barometer reading given in column A the test exposures of the flame should begin the number of degrees centigrade given in column B below the apparent flash point as determined by a preliminary test.

TABLE 1.—*Correction of flash point to a barometric pressure of 760 mm.*

A Barometer reading (mm.).	B Correction (°C.).
685 to 695	9.0
695 to 705	9.5
705 to 715	10.0
715 to 725	10.5
725 to 735	11.0
735 to 745	11.0
745 to 755	11.5
755 to 765	12.0
765 to 775	12.0
775 to 785	12.5

Digitized by Google Original from PRINCETON UNIVERSITY

PRELIMINARY TESTS.

The approximate flash point of an oil to be tested should be first ascertained by a preliminary test. The test should be carefully repeated, beginning some 5° C. below the approximate flash point.

FILLING AND WARMING THE BATH.

After ascertaining the temperature at which the slide should be first opened (see paragraph above), the tester is leveled on a flat-topped table and the bath filled with water or oil as the case may be and warmed to a temperature of 10° C. below the approximate flash point as determined in the preliminary test.

FILLING AND ADJUSTING THE TESTER.

The sample and the oil cup must first be brought to a temperature of about 10° C. below the approximate flash point of the oil, by standing the cup in an ice mixture or warming the sample as may be found necessary before the cup is adjusted in the bath. The lower edge of the overflow aperture is greased on its outer side to induce ready overflow when the oil expands. The clean, dry cup is then placed in the bath, the sample is run into the cup with the aid of a glass pipette until the filling point (see p. 12 and fig. 1) just disappears under the surface as seen by light reflected from the surface of the oil. Care must be taken not to splash the oil onto the sides of the cup and not to have froth formed on the oil. All bubbles on the surface of the oil must be pricked with a heated wire. In case too much oil has been accidentally run into the cup, the cup must be emptied, washed clean with a good solvent, wiped dry, and a fresh filling made. After the filling is correctly done, adjust the cover and thermometer immediately, light the test flame, and adjust it to the size of the ivory bead on the cover, that is, so that it will burn 0.1 cubic foot of coal gas per hour. Then light the gas flame below the bath and adjust to such a height, as determined by preliminary tests, that the temperature of the oil will rise at the rate of from 2° to 3° C. per minute.

MAKING THE TEST.

Allow the apparatus to stand 10 minutes, to give time for the oil vapors to accumulate, meanwhile stirring regularly and constantly at one revolution per second, then warm to within 5° C. of the flash point and expose the test flame for exactly one second by means of the mechanism provided on the cover. Continue stirring and making the exposure at each 0.5° C. rise in the temperature until the flash occurs. Particular care must be taken that the cup is not subjected to drafts during the test and that the breathing of the operator is

Original from PRINCETON UNIVERSITY

not allowed to interfere, particularly at the moment the test flame is exposed to the vapors. It will be noted that at about 5° C. below the flash point, the test flame, as it is exposed to the vapors, will be surrounded by a pale blue halo, which gradually increases in intensity until a sudden inflammation or gentle explosion of the vapors or the "flash" occurs. The temperature at which this occurs, as registered by the thermometer in the oil, is the flash point. With fuel oil residues or with poorly refined oils from which a small quantity of low-flashing fractions is continually being liberated, this halo may first appear as much as 30° C. below the flash point.

The test should always be repeated with a fresh sample. The first sample should be thrown away, the cup washed with gasoline, wiped dry, the cup and water bath cooled to the proper temperature, and the test repeated exactly as described above. Duplicate tests should agree within 0.5° C. The mean of the two readings, if good agreement is noted, corrected for barometric pressure (see Table 2) is considered the flash point of the oil.

THE PENSKY-MARTENS TESTER.

The Pensky-Martens tester (fig. 2) is of the same dimensions and general construction as the Abel-Pensky (fig. 1), but differs from it in that the Pensky-Martens tester is fitted with a heavy outer shell of metal, which acts as a metal bath, instead of with a water bath or oil bath like the Abel-Pensky. Figure 1 shows the Abel-Pensky tester fitted with a stirrer similar to the stirrer provided for the Pensky-Martens. Figure 2 shows the Pensky-Martens fitted with a filling point like the Abel-Pensky. Each of the testers are shown fitted with overflow cups to allow for the expansion of the oil on warming. The method of testing with the Pensky-Martens is the same as with the Abel-Pensky.

BURNING POINT.

The burning point is that temperature at which the oil ignites and continues to burn. To determine the burning point, remove the cover, continue the heating, and expose a test flame to the vapors as nearly as possible in the same manner as when taking the flash point until the oil ignites and continues to burn.

SUBSTITUTE OR SECONDARY TESTERS.

In some instances the cost of the Abel-Pensky and Pensky-Martens testers prohibits their use. In such a case, or when a high degree of accuracy is not required—that is, when the flash point of the oil is not within 5° C. of the minimum legal flash point selected—the flash point may be determined by means of an open-cup tester or a test-tube

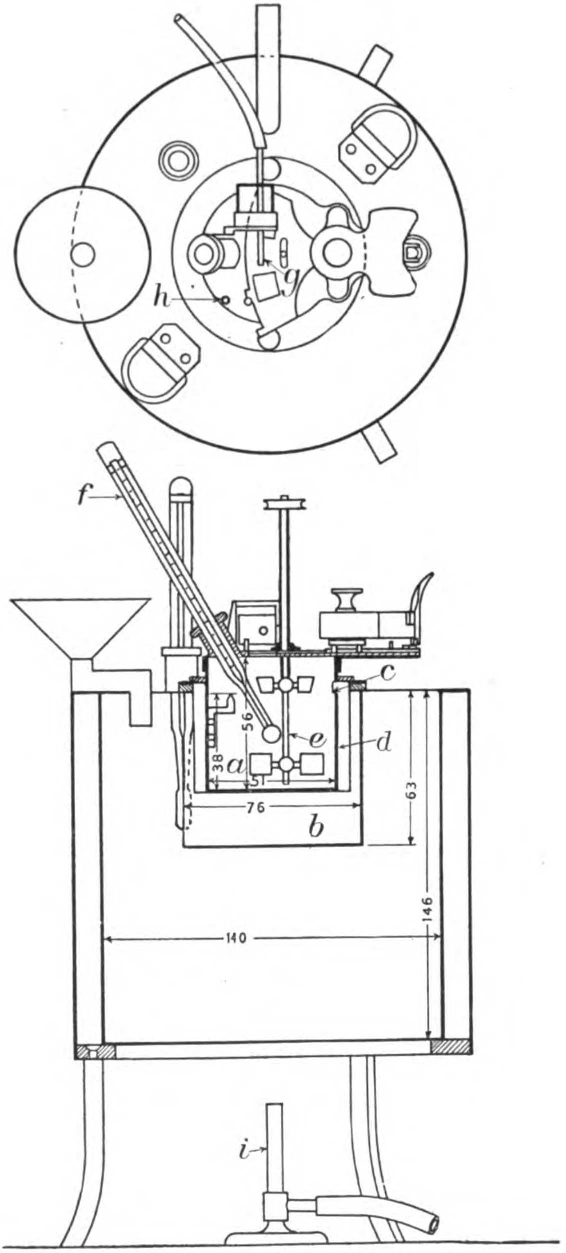


FIGURE 1.—Abel-Pensky flash tester, Bureau of Mines model. *a* oil cup; *b* bath; *c* overflow for oil expanding by heat; *d* overflow cup for oil overflow at *c*; *e* stirrer; *f* thermometer; *g* test flame; *h* ivory bead to judge size of test flame; *i* Bunsen burner.

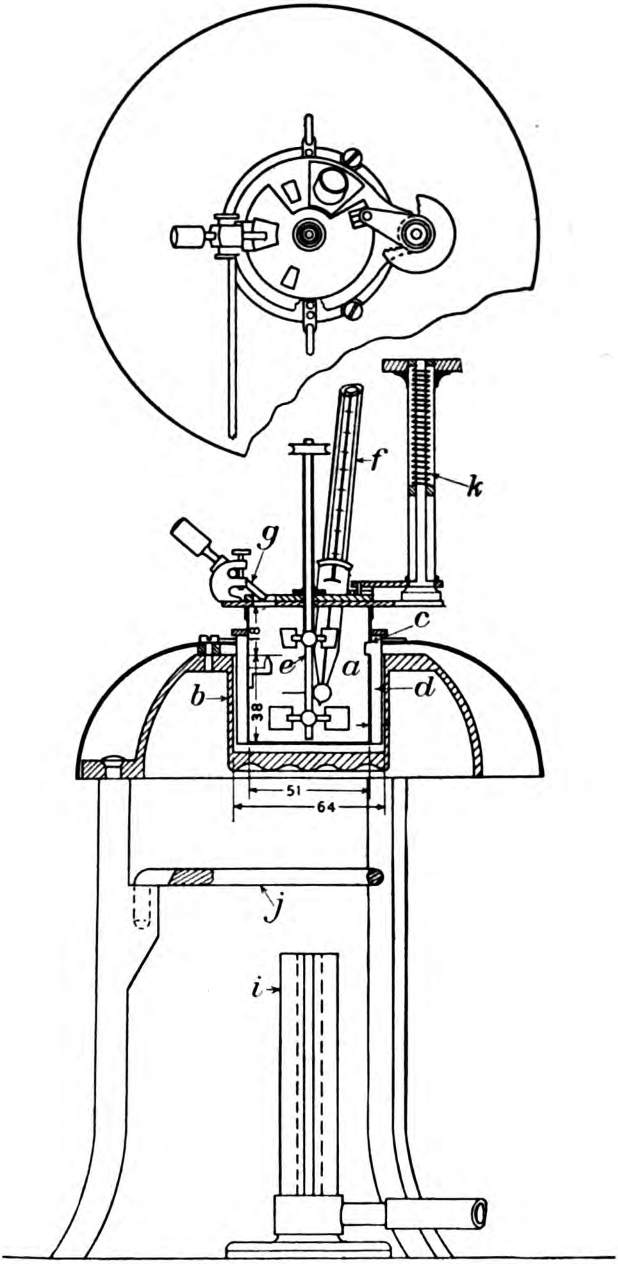


FIGURE 2.—Pensky-Martens flash tester, Bureau of Mines model. *a* oil cup; *b* bath; *c* overflow for oil expanding by heat; *d* overflow cup to collect oil overflowing at *c*; *e* stirrer; *f* thermometer; *g* test flame; *i* Bunsen burner; *j* wire screen; *k* spring to work slide under test flame.

tester. But in all cases where the flash point of the oil is within 5° C. of the legal flash point, and in all cases of controversy or doubt, the Abel-Pensky or the Pensky-Martens tester should be used.

THE OPEN-CUP TEST.

The open-cup tester is used in testing for approximate flash points only. A simple open-cup tester (see p. 8) that may be used for such testing is as follows:

A glass beaker or metal cup of approximately the same dimensions as the Abel-Pensky and Pensky-Martens testers—that is, 5.0 cm. in diameter and 5.5 cm. in depth—is filled to within 1.8 cm. of its upper rim with the oil to be tested. In testing lamp oils the cup is supported in a water bath by a flange at its upper edge, and in testing oils with higher flash points, the cup is supported on a sand bath. A thermometer is supported with its bulb immersed in the oil. A test-flame burner is made by drawing a piece of hard glass tubing to a capillary about 1 mm. in diameter, to which gas is supplied. The flame is adjusted to 3 mm. cross section. The bath is provided with an ordinary Bunsen burner. The method of testing is as nearly as possible like that in official tests with the Abel-Pensky and Pensky-Martens testers.

THE TEST-TUBE TESTER.

A simple and inexpensive tester, based on the principle developed by Victor Meyer, Haass, and others (106 to 110), which will show whether or not a lamp oil will flash at any given temperature, and may be used in ordinary work, is made as follows:

A glass test tube approximately 2 cm. in diameter and 15 cm. long is one-quarter filled with the oil to be tested. The tube is loosely closed with a cork and is immersed to the cork in a water bath warmed to the desired temperature until the temperature of the oil has reached the temperature of the bath. The tube is then removed from the water bath and vigorously shaken. The tube is again immersed in the bath for a moment to equalize the temperature and to allow the vapor to settle. The tube is then removed from the bath, the cork withdrawn in the immediate vicinity of a flame, and the vapors exposed for ignition. Failure of a flash or burning will denote that the oil will not flash at this particular temperature. If that temperature is the legal minimum flash point the oil will have satisfactorily withstood the test. If the test is carefully made, and concordant results are obtained on repetition, it may be trusted for ordinary testing.

TABLE 2.—*Correction of flash point for normal barometric pressures.*

[Reading of barometer, mm.]

Flash point, °C.

760	650	655	660	665	670	675	680	685	690	695	700	705	710	715
19.0	15.5	15.6	15.7	15.8	15.9	16.1	16.2	16.4	16.6	16.7	16.9	17.1	17.3	17.4
19.5	16.0	16.1	16.2	16.3	16.4	16.6	16.7	16.9	17.1	17.2	17.4	17.6	17.8	17.9
20.0	16.5	16.6	16.7	16.8	16.9	17.1	17.2	17.4	17.6	17.7	17.9	18.1	18.3	18.4
20.5	17.0	17.1	17.2	17.3	17.4	17.6	17.7	17.9	18.1	18.2	18.4	18.6	18.8	18.9
21.0	17.5	17.6	17.7	17.8	17.9	18.1	18.2	18.4	18.6	18.7	18.9	19.1	19.3	19.4
21.5	18.0	18.1	18.2	18.3	18.4	18.6	18.7	18.9	19.1	19.2	19.4	19.6	19.8	19.9
22.0	18.5	18.6	18.7	18.8	18.9	19.1	19.2	19.4	19.6	19.7	19.9	20.1	20.3	20.4
22.5	19.0	19.1	19.2	19.3	19.4	19.6	19.7	19.9	20.1	20.2	20.4	20.6	20.8	20.9
23.0	19.5	19.6	19.7	19.8	19.9	20.1	20.2	20.4	20.6	20.7	20.9	21.1	21.3	21.4
23.5	20.0	20.1	20.2	20.3	20.4	20.6	20.7	20.9	21.1	21.2	21.4	21.6	21.8	21.9
24.0	20.5	20.6	20.7	20.8	20.9	21.1	21.2	21.4	21.6	21.7	21.9	22.1	22.3	22.4
24.5	21.0	21.1	21.2	21.3	21.4	21.6	21.7	21.9	22.1	22.2	22.4	22.6	22.8	22.9
25.0	21.5	21.6	21.7	21.8	21.9	22.1	22.2	22.4	22.6	22.7	22.9	23.1	23.3	23.4
25.5	22.0	22.1	22.2	22.3	22.4	22.6	22.7	22.9	23.1	23.2	23.4	23.6	23.8	23.9
26.0	22.5	22.6	22.7	22.8	22.9	23.1	23.2	23.4	23.6	23.7	23.9	24.1	24.3	24.4
26.5	23.0	23.1	23.2	23.3	23.4	23.6	23.7	23.9	24.1	24.2	24.4	24.6	24.8	24.9
27.0	23.5	23.6	23.7	23.8	23.9	24.1	24.2	24.4	24.6	24.7	24.9	25.1	25.3	25.4
27.5	24.0	24.1	24.2	24.3	24.4	24.6	24.7	24.9	25.1	25.2	25.4	25.6	25.8	25.9
28.0	24.5	24.6	24.7	24.8	24.9	25.1	25.2	25.4	25.6	25.7	25.9	26.1	26.3	26.4
28.5	25.0	25.1	25.2	25.3	25.4	25.6	25.7	25.9	26.1	26.2	26.4	26.6	26.8	26.9
29.0	25.5	25.6	25.7	25.8	25.9	26.1	26.2	26.4	26.6	26.7	26.9	27.1	27.3	27.4
29.5	26.0	26.1	26.2	26.3	26.4	26.6	26.7	26.9	27.1	27.2	27.4	27.6	27.8	27.9
30.0	26.5	26.6	26.7	26.8	26.9	27.1	27.2	27.4	27.6	27.7	27.9	28.1	28.3	28.4
30.5	27.0	27.1	27.2	27.3	27.4	27.6	27.7	27.9	28.1	28.2	28.4	28.6	28.8	28.9
31.0	27.5	27.6	27.7	27.8	27.9	28.1	28.2	28.4	28.6	28.7	28.9	29.1	29.3	29.4
31.5	28.0	28.1	28.2	28.3	28.4	28.6	28.7	28.9	29.1	29.2	29.4	29.6	29.8	29.9
32.0	28.5	28.6	28.7	28.8	28.9	29.1	29.2	29.4	29.6	29.7	29.9	30.1	30.3	30.4
32.5	29.0	29.1	29.2	29.3	29.4	29.6	29.7	29.9	30.1	30.2	30.4	30.6	30.8	30.9
33.0	29.5	29.6	29.7	29.8	29.9	30.1	30.2	30.4	30.6	30.7	30.9	31.1	31.3	31.4
33.5	30.0	30.1	30.2	30.3	30.4	30.6	30.7	30.9	31.1	31.2	31.4	31.6	31.8	31.9
34.0	30.5	30.6	30.7	30.8	30.9	31.1	31.2	31.4	31.6	31.7	31.9	32.1	32.3	32.4
34.5	31.0	31.1	31.2	31.3	31.4	31.6	31.7	31.9	32.1	32.2	32.4	32.6	32.8	32.9
35.0	31.5	31.6	31.7	31.8	31.9	32.1	32.2	32.4	32.6	32.7	32.9	33.1	33.3	33.4

Flash point, °C.

720	725	730	735	740	745	750	755	**760**	765	770	775	780	785
17.6	17.8	18.0	18.1	18.3	18.5	18.7	18.8	**19.0**	19.2	19.4	19.5	19.7	19.9
18.1	18.3	18.5	18.6	18.8	19.0	19.2	19.3	**19.5**	19.7	19.9	20.0	20.2	20.4
18.6	18.8	19.0	19.1	19.3	19.5	19.7	19.8	**20.0**	20.2	20.4	20.5	20.7	20.9
19.1	19.3	19.5	19.6	19.8	20.0	20.2	20.3	**20.5**	20.7	20.9	21.0	21.2	21.4
19.6	19.8	20.0	20.1	20.3	20.5	20.7	20.8	**21.0**	21.2	21.4	21.5	21.7	21.9
20.1	20.3	20.5	20.6	20.8	21.0	21.2	21.3	**21.5**	21.7	21.9	22.0	22.2	22.4
20.6	20.8	21.0	21.1	21.3	21.5	21.7	21.8	**22.0**	22.2	22.4	22.5	22.7	22.9
21.1	21.3	21.5	21.6	21.8	22.0	22.2	22.3	**22.5**	22.7	22.9	23.0	23.2	23.4
21.6	21.8	22.0	22.1	22.3	22.5	22.7	22.8	**23.0**	23.2	23.4	23.5	23.7	23.9
22.1	22.3	22.5	22.6	22.8	23.0	23.2	23.3	**23.5**	23.7	23.9	24.0	24.2	24.4
22.6	22.8	23.0	23.1	23.3	23.5	23.7	23.8	**24.0**	24.2	24.4	24.5	24.7	24.9
23.1	23.3	23.5	23.6	23.8	24.0	24.2	24.3	**24.5**	24.7	24.9	25.0	25.2	25.4
23.6	23.8	24.0	24.1	24.3	24.5	24.7	24.8	**25.0**	25.2	25.4	25.5	25.7	25.9
24.1	24.3	24.5	24.6	24.8	25.0	25.2	25.3	**25.5**	25.7	25.9	26.0	26.2	26.4
24.6	24.8	25.0	25.1	25.3	25.5	25.7	25.8	**26.0**	26.2	26.4	26.5	26.7	26.9
25.1	25.3	25.5	25.6	25.8	26.0	26.2	26.3	**26.5**	26.7	26.9	27.0	27.2	27.4
25.6	25.8	26.0	26.1	26.3	26.5	26.7	26.8	**27.0**	27.2	27.4	27.5	27.7	27.9
26.1	26.3	26.5	26.6	26.8	27.0	27.2	27.3	**27.5**	27.7	27.9	28.0	28.2	28.4
26.6	26.8	27.0	27.1	27.3	27.5	27.7	27.8	**28.0**	28.2	28.4	28.5	28.7	28.9
27.1	27.3	27.5	27.6	27.8	28.0	28.2	28.3	**28.5**	28.7	28.9	29.0	29.2	29.4
27.6	27.8	28.0	28.1	28.3	28.5	28.7	28.8	**29.0**	29.2	29.4	29.5	29.7	29.9
28.1	28.3	28.5	28.6	28.8	29.0	29.2	29.3	**29.5**	29.7	29.9	30.0	30.2	30.4
28.6	28.8	29.0	29.1	29.3	29.5	29.7	29.8	**30.0**	30.2	30.4	30.5	30.7	30.9
29.1	29.3	29.5	29.6	29.8	30.0	30.2	30.3	**30.5**	30.7	30.9	31.0	31.2	31.4
29.6	29.8	30.0	30.1	30.3	30.5	30.7	30.8	**31.0**	31.2	31.4	31.5	31.7	31.9
30.1	30.3	30.5	30.6	30.8	31.0	31.2	31.3	**31.5**	31.7	31.9	32.0	32.2	2.4
30.6	30.8	31.0	31.1	31.3	31.5	31.7	31.8	**32.0**	32.2	32.4	32.5	32.7	32.9
31.1	31.3	31.5	31.6	31.8	32.0	32.2	32.3	**32.5**	32.7	32.9	33.0	33.2	33.4
31.6	31.8	32.0	32.1	31.3	32.5	32.7	32.8	**33.0**	33.2	33.4	33.5	33.7	33.9
32.1	32.3	32.5	32.6	32.8	33.0	33.2	33.3	**33.5**	33.7	33.9	34.0	34.2	34.9
32.6	32.8	33.0	33.1	33.3	33.5	33.7	33.8	**34.0**	34.2	34.4	34.5	34.7	34.9
33.1	33.3	33.5	33.6	33.8	34.0	34.2	34.3	**34.5**	34.7	34.9	35.0	35.2	35.4
33.6	33.8	34.0	34.1	34.3	34.5	34.7	34.8	**35.0**	35.2	35.4	35.5	15.7	35.9

BIBLIOGRAPHY.

Herewith is presented a bibliographic list of articles and books cited in the text of this report. The publications are numbered according to the order in which the text reference is made.

1. Allen, I. C., The preparation of specifications for petroleum products. Technical Paper 36, Bureau of Mines, 1913, p. 9.

2. Aisinmann, S., Die gesetzliche Normirung des Testpunktes von Petroleum. Chem. Ztg., vol. 20, May 16, 1896, p. 396.

3. Piek, P., Ueber die Zwechmässigkeit der Bestimmung des Flamm- und Brennpunktes bei Schmierölen. Chem. Ztg., Rep., vol. 33, Mar. 18, 1909, p. 162; Oest. Poly. Ztschr., 1909, pp. 10–11.

6. Chemische Zeitung., Zur petroleumfrage in England. Vol. 20, Mar. 2, 1896, p. 361.

7. Mickolls, A. H., A method for the classification of the hazardous properties of certain liquids. Quarterly of the National Fire Protection Association of the United States, vol. 1, April, 1908, p. 68.

8. Robinson, J. A., Denatured alcohol. Quarterly of the National Fire Protection Association of the United States, vol. 1, 1908, p. 92.

9. National Board of Fire Underwriters. List of gas, oil, mechanical, and chemical appliances. Special Bulletin, January, 1913.

10. Wiebe, H. F., Zur internationalen Vereinheitlichung der Flammpunktsbestimmungen. Petroleum, vol. 7, Jan. 17, 1912, p. 406.

11. Syme, W. A., Oil Bulletin, North Carolina Department of Agriculture, No. 1, vol. 31, Jan. 1910, p. 11.

12. Abel, F. A., The flashing test for petroleum. Jour. Soc. Chem. Ind., vol. 1, 1862, pp. 471–478.

13. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, pp. 545–596.

14. Board of Trade, Standards Office, Petroleum Act 1879 (42 and 43 Vict., c. 47).

15. Steuart, D. R., The standard for flash point for mineral oils. Jour. Soc. Chem. Ind., vol. 15, May 30, 1896, pp. 335–336.

16. Chamberlain, C. D., On uniform oil inspection. Views of the National Petroleum Association to State delegates in conference on uniform legislation, under the auspices of the National Civic Federation, Washington, D. C., January, 1910, p. 1.

17. Redwood, Boverton, The Tagliabue open flash-point tester. Petroleum and its products, vol. 2, 1906, p. 546.

18. Redwood, Boverton, The Tagliabue closed flash-point tester. Petroleum and its products, vol. 2, 1906, p. 576.

19. Redwood, Boverton, The Elliot flash-point tester. Petroleum and its products, vol. 2, 1906, p. 577.

20. Redwood, Boverton, The Foster flash-point tester. Petroleum and its products, vol. 2, 1906, p. 581.

21. Abel, F. A., Der Abel Entzündungsapparat. Neue Wochenschr. Oel. Fettw., 1879, p. 105; Ztschr. Chem. Grossgew, vol. 4, p. 63; Ztschr. anal. Chem., 1881, p. 17; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 558–571; Holde, D., Untersuchung der Mineralöle und Fette, 1909, p. 52.

22. Redwood, Boverton, Pensky-Martens flash-point tester for lubricating oils; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 593; Holde, D., Untersuchung der Mineralöle und Fette, 1909, p. 133; Benedikt-Ulzer, Analyse der Fette und Wachsarten, 1908, p. 386.

23. Syme, W. A., Oil Bulletin, North Carolina department of agriculture, No. 1, vol. 31, January, 1910, p. 11.

24. Journal du Pétrole, Flammpunktsprüfung für Brennöle, vol. 10, 1910, p. 101; Chem. Rev. Fett. Harz. Ind., vol. 17, June, 1910, p. 141.

25. Journal du Pétrole, Les épreuves d'inflammabilité du lampant, vol. 11, Apr. 15-20, 1911, p. 101.

26. Journal du Pétrole, Les épreuves d'inflammabilité des huiles minérales, vol. 12, 1912, p. 10.

27. Aisinmann, S., Ueber die Flammpunktsbestimmung der Mineralschmieröle., Dinglers Polyt. Jour., vol. 294, p. 68.

28. Allen, J., Die Bestimmung der Feuergefährlichkeit des Petroleums, Deut. Ind. Ztg., 1868, p. 437; Wagner's Jahresb., 1868, p. 729.

29. Redwood, Boverton, The Arnaboldi flash-point tester. Petroleum and its products, vol. 2, 1906, p. 548.

30. Attfield, J., On the igniting point of petroleum. Pharm. Jour., ser. 2, vol. 8, 1867, pp. 318-325; ser. 3, vol. 2, 1871, p. 43; Chem. News, 14, 1866, pp. 257-258; Wagner's Jahresb., 1867, p. 725.

31. Chandler, C. F., Tagliabue's open flash tester. Report on Petroleum, 1871, p. 36.

32. Chandler, C. F., The closed flash-point tester of Tagliabue, the pyrometer. Report on Petroleum, 1871, p. 36; Hannover Monatschr. von Skalweit, 1879, p. 95; Bolleys Handbuch Technische Chemische Untersuchungen, 4th ed., p. 607; 5th ed., p. 667; Ztschr. anal. Chem., 1881, p. 8.

33. Zeitschrift der analytische Chemie. Petroleum Entzündungsprüfer, 1881, p. 11; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 549.

34. Redwood, Boverton, The Ehrenberg flash-point tester. Petroleum and its products, vol. 2, 1906, p. 582.

35. Engler, C., Die Prüfung des Petroleums auf seine Feuergefährlichkeit. Ztschr. anal. Chem., vol. 20, 1881, pp. 1-36.

36. Engler, C., and Haass, R., Die Prüfung des Petroleums auf seine Feuergefährlichkeit. Wagner's Jahresb., 1881, pp. 1199-1200.

37. Engler, H., Ueber die Bestimmung der Fuergefahrlichkeit des Petroleums, Ber. Deut. Chem. Gesell., vol. 12, 1879, p. 2184.

38. Ernecke and Hannemann, Die Bestimmung der Feuergefährlichkeit des Petroleums. Deut. Ind. Ztg., 1870, p. 19; Wagner's Jahresb., 1870, pp. 707, 709.

39. Granier, E., Appareil pour constater le degré d'inflammabilité des huiles de pétrole destinées à l'éclairage. Bull. Soc. Encour. Ind. Nat., vol. 71, 1872, p. 196.

40. Höfer, H., A flash tester for petroleums. Centennial Exposition, Phila., Petroleum Industry of North America, 1876, p. 143.

41. Hutton, Die Bestimmung der Feuergefährlichkeit des Petroleums. Dinglers Polyt. Jour., vol. 192, p. 261.

42. Redwood, Boverton, The Indiana State flash-point tester. Petroleum and its products, vol. 2, 1906, p. 548.

43. Jacobsen, E., Der Entflammungspröber von Abeljanz. Chem. Ind., vol. 4, Aug., 1881, p. 272; Deut. Ind. Ztg., 1881, p. 79.

44. Kyll, Die Bestimmung der Feuergefährlichkeit des Petroleums. Hannover Monatsschr. Skalweit, 1879, p. 92; Leybold's Preisverz, No. 1572, 1880.

45. Lenoir and Foster, Die Bestimmung der Feuergefährlichkeit des Petroleums. Chem. Ztg., 1879, p. 205.

46. Redwood, Boverton, The Minnesota State flash-point tester. Petroleum and its products, vol. 2, 1906, p. 549.

47. Möser, Die Bestimmung der Feuergefährlichkeit des Petroleums. Gebrauchsanweisung, Darmstadt, Marienpl 7.

48. Redwood, Boverton, The Saybolt flash-point tester. Petroleum and its products, vol. 2, 1906, p. 548.

49. Redwood, B., The Squires flash-point tester. Petroleum and its products, vol. 2, 1906, p. 547.

50. Vette, R., Petroleumprüfer. Chem. Centralb., vol. 12, Dec. 21, 1881, p. 812; Ind. Blat., vol. 18, Oct. 15, 1881, p. 322.

51. Warren, H. N., A simple electrical apparatus for determining the flashing point of mineral oils. Chem. News, vol. 62, 1890, p. 311.

52. Weise, V., Die Bestimmung der Feuergefährlichkeit des Petroleums. Polyt. Centralbl., 1871, p. 378; Chem. Centralbl., 1871, p. 327; Deut. Ind. Ztg., 1871, p. 163; Wagner's Jahresb., 1871, p. 863.

53. Courtois, F. A., Flash tester. U. S. patent, Apr. 25, 1905, No. 788250; Jour. Soc. Chem. Ind., vol. 24, Sept. 30, 1905, p. 987; Ztschr. angew. Chem., 1905, p. 847.

54. Kissling, R., Determination of the flashing and ignition points of lubricating oils. Chem. Ztg., 1899, pp. 800–801; Jour. Soc. Chem. Ind., vol. 18, 1899, p. 1114.

55. Künkler, A., Ueber flamm- und Brennpunktsbestimmungen von Mineralschmierölen. Chem. Ztschr., vol. 23, 1899, pp. 166–169.

56. Marcusson, J., Bestimmung des Flamm- und Brennpunktes von Schmierölen im offenen Tiegel. Chem. Ztg., vol. 30, 1906, p. 1183; Chem. Rev. Fett. Harz. Ind., vol. 14, 1907, pp. 11, 54.

57. Marcusson, J., Flammpünktsbestimmüng für Schmiermittel mittels die ofene methode. Chem. Rev. Fett. Harz. Ind., vol. 14, 1907, pp. 9–10; Chem. Abs., June 5, 1907, p. 1478.

58. Stoeber, E., Der Flammpunkt als Hilfsmittel bei Wachsanalysen. Chem. Ztg., vol. 33, 1909, p. 1275; Chem. Rev. Fett. Harz. Ind., vol. 17, January, 1910, p. 16.

59. Redwood, Boverton, The Truemann flash-point tester. Petroleum and its products, vol. 2, 1906, p. 595.

60. Walker, P. H., An apparatus to determine the flash point of lubricants. Bureau of Chem. Bull. 109, U. S. Dept. of Agri., 1910, p. 11.

61. Herbig, W., Zur Bestimmung des Flammpunktes der Mineralöle. Chem. Rev. Fett. Harz. Ind., vol. 12, 1905, pp. 26–30; Jour. Soc. Chem. Ind., vol. 24, Feb. 28, 1905, p. 212.

62. Braun, O., Flash-point tester. Sitz. Ver. Beförd. Gewerbfl. Preuss., 1881, p. 212; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 582.

63. Chandler, C. F., Tagliabue geschlossener Petroleum-prüfungsapparat (Pyrometer). Hannover Monatschr. von Skalweit, 1879, p. 95; Bolleys Handbuch des technische. chemische. Untersuchungen, 4th ed., p. 607; 5th ed., p. 667; Ztschr. anal. Chem., 1881, p. 15.

64. Engler, C., Ein Apparat zur Prüfung des Petroleums. Chem. Ind., vol. 3, 1880, pp. 53–56; Chem. Ztg., vol. 4, Nov. 18, 1880, p. 767.

65. Engler, C., Verbesserte Entzündungsprüfer "Naphtometer." Correspondenzbl. Ver. Analyt. Chemiker, 1880, p. 129; Chem. Ind., vol. 3, Nov. 1880, p. 389.

66. Heumann., Flammpünktpröber Chem. Ind., vol. 7, 1884, p. 188; Posts Chemtech. Anal., 11, 1888, p. 301; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 575.

67. Kuckla, Geschlossene Entznduüngsprüfer. Wagner's Jahresb., 1866, p. 673.

68. Redwood, Boverton, The Luchaire flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 580.

69. Redwood, Boverton, The Mann flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

70. Redwood, Boverton, The Millspaugh flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

71. Parish, Edward, On a new apparatus for testing coal oils. Trans. Am. Pharm. Ass., 1862, pp. 206–209; Wagner's Jahresb., vol. 10, 1864, p. 675; vol. 11, 1865, p. 749; vol. 12, 1866, p. 671; Ztschr. Anal. Chem., vol. 3, 1864, p. 228; vol. 20, 1881, p. 21, Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 580.

72. Redwood, Boverton, The Phlog-elaio-metre flash-point tester. Petroleum and its products, vol. 2, 1906, p. 581.

73. Skalweit, J., Neue apparat für Bestimmung des Entflammbarkeites. Ztschr. anal. Chem., 1881, p. 305.

74. Redwood, Boverton, The Wisconsin flash-point tester. Petroleum and its products, vol. 2, 1906, p. 577.

75. Petroleum world. Closed-cup flash tests; description and method of using an apparatus. Vol. 9, February, 1912, p. 79.

76. Steuart, D. R., Flash point of burning oils. Chem. News, June 3, 1893; Jour. Soc. Chem. Ind., vol. 15, 1896, pp. 173–179; Jour. Ind. Eng. Chem., vol. 1, September, 1909, p. 679.

77. Bernstein, A., Apparat zur Prüfung Entzündbarkeit des Petroleums. Wagner's Jahresb., vol. 25, 1879, p. 1180; Deut. Ind. Ztg., 1879, p. 517; Ztschr. Anal; Chem., 1881, p. 24; Sitzüng Verein Bëforderüng Gewerbfleiss, Preuss, 1879, p 173. Dinglers polyt. Jour. 1881, p. 136; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 582.

78. Braun, O., Verbesserung an dem Abelischen Petroleumprober. Rep. Anal. Chem., vol. 3, Feb. 1, 1883. Chem. Ztg., 1882, p. 1301, German patent 19757; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 572.

79. Engler, C., Erwiderung an A. Berstein's Entzündungsprüfer. Chem. Ind., vol. 3, April, 1880, p. 156.

80. Engler, C., Ein Apparat zur Prüfung des Petroleums. Chem. Ind., vol. 3, February, 1880, p. 53. Ztschr. anal. Chem., vol. 20, 1881, p. 27; Elktrische Flammpunktpröber, Posts Chem.-tech. Anal., vol. 2, 1888, p. 299; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 573.

81. Redwood, Boverton, The Gawalowski flash-point tester. Petroleum and its products, vol. 2, 1906, p. 585.

82. Granier, E., Geschlossene Entzündungsprüfer. Polyt. Centralbl., 1873, p. 1029; Compt. Rend. Soc. Encon. vol. 15, 1872; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 579.

83. Gray, J., Apparatus for determining the flash points of heavy mineral oils. Jour. Soc. Chem. Ind., vol. 10, Apr. 30, 1891, p. 348; Jour. Chem. Soc., vol. 62, 1892, p. 542; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 595.

84. Harker, J. A., and Higgins, W. F., On the methods and apparatus used in petroleum testing. Collected Researches, Nat. Phys. Lab., vol. 8, 1911, p. 19; Petroleum World, July, August, September, 1911; Petroleum, vol. 7, Jan. 3, 1912, p. 350.

85. Holde, D., Die Flammpunktsprüfung von Mineralschmierölen. Mitth. k. techn. Versuchsanst, vol. 7, 1889, pp. 64–72; Jour. Soc. Chem. Ind., vol. 8, Sept. 30, 1889, p. 734.

86. Holde, D., An electrically heated Pensky flash tester. Petroleum, vol. 4, 1908, p. 14; Chem. Ztg., vol. 32, 1908, p. 650; Chem. Abs., vol. 3, 1909, p. 707.

87. Jacobsen, E., Der "Taucher" Entflammungspröber von O. Braum. Chem. Ind., vol. 4, July, 1881, p. 229. German patent 14022, Aug. 31, 1880.

88. Redwood, B., The Keates flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 550.

89. Künkler, Die Truemann Flammpunktpröber für Schmiermittel. Die Maschinenschmierung, 1894; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 595.

90. Letheby, Flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 573.

91. Redwood, B., The Pease flash-point tester. Petroleum and its products, vol. 2, 1906, p. 573.

92. Saybolt, G., Die Bestimmung der Feuergefährlichkeit des Petroleums. Chem. Ind., 1880, p. 55; Ztschr. Chem. Grossgew, 1879, p. 63.

93. Saybolt, G., Electrisch Entzündungsprüfer. Chem. Ind., 1880, p. 55; Ztschr. Chem. Grossgew, 1879, p. 63; Ztschr. Chem., 1881, p. 13.

94. Schmitz, Ruhrvorrichtung; für den Martens-Pensky-Apparat. Chem. Ztg., vol. 33, 1909, pp. 1107, 1221, 1304; Chem. Abs., vol. 4, Jan. 20, 1910, p. 131; Chem. Rev. Fett. Harz. Ind., vol. 16, November, 1909, p. 281.

95. Sintenis, Petroleum "Pyrometer" oder Entflammbarbeitsapparat. Hannover Monatschr. von Skalweit, 1879, p. 96; Chem. Ztg., 1879, p. 254; Ztschr. anal. Chem., 20, 1881, pp. 20, 21.

96. Vette, Flash-point tester. Dinglers Polyt. Jour., 1862, p. 476; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

97. Weber, R., Petroleumprüfüng auf seine Entzündlichkeit. Ind. Blätter, 1878, p. 12; Wagner's Ber., 1877, p. 1033; Deut. Ind. Ztg., 1878, p. 6.

98. Wiebe, H. F., Obere Brauchbarkeitsgrenze des Abel-Penskyschen Apparates und seine Vergleichung mit dem Penskyschen Flammpunktprüfer. Petroleum, vol. 8, Oct. 2, 1912, p. 16.

99. Wiebe, H. F., The upper limit of usability of the Abel-Pensky apparatus and its comparison with the Pensky flash-point tester. Proceedings 8th Inter. Cong. Applied Chem., vol. 10, p. 303–307. Chem. Abs., vol. 6, Nov. 10, 1912, p. 3178.

100. Wiebe, H. F., and Hebe, P., Comparison of English and German flash testers. Petroleum, vol. 5, 1910, p. 885. Chem. Abs., vol. 4, Sept. 10, 1910, p. 2370.

101. Beilstein, F. F., Ueber Petroleumprüfung. Zeit. anal. Chem., vol. 22, 1883, pp. 309–316; Ztschr. anal. Chem., 23, 1883, p. 312; Wagner's Jaluish., 2, 1885, p. 2177; Chem. Centralbl., 1885, p. 286; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

102. Liebermann, L., Eine neue Methode zur Bestimmung des Entflammungspunktes von Petroleum. Ztschr. anal. Chem., vol. 21, 1882, p. 321–329; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

103. Reythien, A., and Hempel, H., Die Bestimmung des Entflammungspunktes von Flüssigkeiten. Farben Ztg., vol. 13, 1907; Chem. Rev. Fett. Harz. Ind., pt. 3, 1908, pp. 57–60.

104. Stoddard, J. T., On the determination of the flashing point of petroleum. Am. Chem. Jour., vol. 4, 1882, pp. 285–288, 293–295; vol. 5, 1883, pp. 459–460; vol. 6, 1884, pp. 18–23; Jour. Chem. Soc., vol. 46, 1884, p. 1431.

105. Stoddard, J. T., Determination of flash point of petroleum. Jour. Am. Chem. Soc., vol. 5, 1883, p. 517; Ber., Deut. chem. Gesell., vol. 15, 1882, p. 2555; Jour. Chem. Soc., vol. 44, 1883, p. 383; Chem. News, 1882, p. 297.

106. Haass, R., Zur Prüfung des Petroleums auf seine Feuergefährlichkeit. Chem. Ind., vol. 3, 1880, pp. 123–126.

107. Haass, R., Zur Prüfung des Petroleums auf seine Feuergefährlichkeit. Chem. Ind., Apr. 3, 1880, p. 123; Ztschr. anal. Chem., 1881, p. 29; Ztschr. anal. Chem., vol. 20, 1880, p. 29; Petroleum and its products, vol. 2, 1906, p. 575.

108. Hörler, H., Die Entflammungstemperatur des Petroleums in Rücksicht auf Form and Grösse der Gefässe. Dinglers Polyt. Jour., vol. 234, p. 52; Chem. Ind., vol. 2, p. 431; Wagner's Jahresb., 1879, p. 1175; Ztschr. anal. Chem., 1881, p. 28.

109. Meyer, V., Die Bestimmung des Entflammungspunktes des Petroleums. Wagner's Jahresb., 1879, p. 1175; Fittica Jahresb., 1879, p. 1145; Ztschr. anal. Chem., 1881, p. 28.

110. Meyer, V., Gutachten betreffend eine Verordnung über den Verkehr mit Petroleum u. s. w. feuergefährliche Flüssigkeiten erstättet. Chem. Ind., vol. 2, Oct. 1879, p. 352; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 575.

111. Charitschkoff, K. W., Der Zusammenhang zwischen Entflammungstemperatur und der Dampftension brennbarer Flüssigkeiten mit niedriger Siedetemperatur derselben. Chem. Ztg., vol. 32, Apr. 11, 1908, p. 382; Russ. Phys. Chem. Soc. St. Petersburg, vol. 1, Nov. 14, 1907.

112. Bolley and Kopp, Die Geissler Methode der Bestimmung der Feuergefährlichkeit des Petroleums, mittels "Vaporimeter." Handbuch Technische Chemische Untersuchungen, 5th ed., p. 740.

113. Meusel, Die Bestimmung der Feuergefährlichkeit des Petroleums. Polyt. Centralbl., 1872, p. 310; Deut. Ind. Ztg., 1872, p. 155; Chem. Centralbl., 1872, p. 234; Wagner's Jahresb., 1872, p. 847.

114. Salleron, J., and Urbain, V., Apparat für die Bestimmung des Entflammbarkeit des Petroleums. Ztschr. anal. Chem., vol. 5, 1881, p. 247; Dinglers Polyt. Jour., vol. 181, p. 397, vol. 232, p. 354; Deut. Ind. Ztg., 1866, p. 164; Wagner's Jahresb., 1866, p. 671; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 585; Ann. gen. Civil, 5, 1866, p. 154.

115. Salleron, J., and Urbain, V., Nouvelle méthode d'essai des huiles minérales. Compt. Rend. vol. 62, 1886, p. 43.

116. Vanderweyde, P. H., Improved fire test of illuminating petroleum, without the use of fire. Amer. Gaslight Jour., vol. 15, 1871, pp. 119, 120, 133; Jour. Chem. Soc., vol. 10, 1872, p. 272; Sci. Am., 1871, p. 162; Dinglers Polyt. Jour., vol. 202, p. 301; Ztschr. anal. Chem., vol. 2, p. 338; Polyt. Centralbl., 1872, p. 138; Deut. Ind. Ztg., 1871, p. 478; Wagner's Jahresb., 1871, p. 862.

117. Barran, d'A. de, Sur le procès Granier pour diminuer le point d'inflammation des pétroles. Compt. Rend., vol. 73, 1871, p. 490.

118. Beilstein, F. P., Die Prüfung des Petroleums. Chem. Centralb., 1885, p. 286.

119. Rosenbladt, Th., Bestimmung der Entflammungstemperatur des Petroleums. Chem. Ztg., vol. 10, 1886, p. 1587; Jour. Soc. Chem. Ind., vol. 6, Apr. 29, 1887, p. 304; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 587.

120. Dvorkovitz, P., Relation of flashing points to the boiling points of (petroleum) illuminating oils. Petrol. Rev., vol. 13, 1905, pp. 7–8, 24–25; Jour. Soc. Chem. Ind., vol. 24, Aug. 15, 1905, p. 838.

121. Schottky, A., Tagliabue's offener Entzündungsprüfer. Chem. Ztg., vol. 3, Apr. 17, 1879, p. 193, Apr. 24, p. 205.

122. Martens, A., Ueber die Flammpunktsbestimmungen von Schmierölen. Mitteilungen k. Versuchsanstalt, vol. 11, 1893, p. 37–45; Jour. Soc. Chem. Ind., vol. 12, Nov. 30, 1893, p. 936.

123. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 557.

124. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 559.

125. Abel, F. A., Entflammungspunkt des Petroleums. Wagner's Jahresb., 1883, p. 1600.

126. Steuart, D. R., The Abel test and the standard of safety for mineral oil. Chem. News, vol. 70, 1894, p. 284, 285.

127. Holde, D., Die Berücksichtigung der Ausdehnung der Oele bei der Flammpunktbestimmung von hochsiedenden Mineralölen. Ztschr. angew. Chem., 1897, pp. 51–52; Jour. Soc. Chem. Ind., vol. 5, 1897, p. 322.

128. Martens, A., Die Flammpunktsprüfung von Mineralschmierolen. Polyt. Jour., vol. 295, 1895, p. 189.

129. Calvert, F. C., On the testing of petroleum spirit. Chem. News, vol. 21, Feb. 25, 1870, p. 85.

130. Meyer, F., Thermometerkorrekturen bei der Bestimmung des Flamm-und Brennpunktes von Oelen. Ztschr. angew. Chem., vol. 23, p. 55; Chem. Rev. Fett. Harz. Ind., vol. 17, pt. 3, March, 1910, p. 59; Petroleum, vol. 5, Feb. 16, 1910, p. 577; Chem. Abs., vol. 4, May 20, 1910, p. 1367.

131. Jenkins, J. H. B., The Abel flash-point test. Chem. News, 71, 1895, pp. 106–107.

132. Abel, F. A., and Redwood, Boverton, Note on the employment of the Abel leum testing apparatus in tropical climates. Chem. News, May 2, 1884; Jour. Soc. Chem. Ind., vol. 3, May 29, 1884, p. 318.

133. Abel, F. A., and Redwood, Boverton, Petroleum testing in tropical climates with Abel's apparatus. Chem. News, vol. 49, 1884, p. 196.

134. Paul, B. H., The mode of testing mineral oils used for lamps. Chem. News, vol. 21, Jan. 7, 1870, p. 2.

135. Zaloziecki, R. Über die Feuergefährlichkeit des Petrols. Chem. Centralbl., vol. 68, pt. 1, 1897, pp. 212–213; Milch. Ztg., 20, p. 821, pp. 837–839.

136. Peltzer, R., Ueber die Entflammbarkeit des Petroleums und des Schieferöles. Dinglers Polyt. Jour., vol. 189, 1868, p. 61–63; Jour. Franklin Inst., vol. 86, 1868, pp. 333–336.

137. Sherman, H. C., Gray, T. T., and Hammerschlag, H. A., Comparison of the calculated and determined viscosities and flashing and burning points of oil mixtures. Jour. Ind. Eng. Chem., vol. 1, 1909, p. 13; Chem. Abs., May 10, 1909, p. 1079.

138. Charitschkow, K., The influence of water upon the flashing point and viscosity of mineral lubricating oils and naphtha residues. Vestnik zhirov. prom., vol. 8, 1907, p. 60; Chem. Ztg., vol. 31, 1907, p. 376; Chem. Rev. Fett. Harz. Ind., vol. 14, p. 225; Chem. Ztg., Rep. 1907; Chem. Abs., vol. 2, Jan. 10, 1908, p. 176; Feb. 10, p. 456; Jour. Soc. Chem. Ind., vol. 26, Sept. 16, 1907, p. 958.

139. Sadtler, S. S., Influence of water upon the flashing point and viscosity of mineral lubricating oils and naphtha residues. Chem. Abs., vol. 2, pt. 1, 1908, p. 176.

140. Matuschek, J., The influence of the water present on the flash point and combustion point of petroleum. Oesterr. Chem. Zeit., vol. 4, 1901, p. 200; Chem. News, vol. 85, 1902, p. 267; Jour. Soc. Chem. Ind., vol. 21, July 15, 1902, p. 909.

141. Allen, I. C., and Jacobs, W. A., Methods for the determination of water in petroleum and its products. Technical Paper 25, Bureau of Mines, 1912, p. 8.

142. Journal of the Society of Chemical Industry. Testing flashing point of petroleum. Vol. 3, Jan. 29, 1884, p. 8.

143. Kissling, R., Die Prüfung sogenante hochtestiger Leuchtöle (Sicherheitsöle auf ihre Entflammbarkeit. Chem. Zeit., vol. 16, 1892, p. 1070; Jour. Soc. Chem. Ind., vol. 12, May 31, 1893, p. 467.

144. Allen, I. C., Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas. Technical Paper 3, Bureau of Mines, 1911, pp. 7–11.

○

Technical Paper 49a. (2d. ed.) Petroleum Technology 10

UNIVERSITY LIBRARY
MAY 11 1914
PRINCETON, N. J.

DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

THE FLASH POINT OF OILS

METHODS AND APPARATUS FOR ITS DETERMINATION

BY

IRVING C. ALLEN AND A. S. CROSSFIELD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1914

Original from PRINCETON UNIVERSITY

The Bureau of Mines, in carrying out one of the provisions of its organic act—to disseminate information concerning investigations made—prints a limited free edition of each of its publications.

When this edition is exhausted copies may be obtained at cost price only through the Superintendent of Documents, Government Printing Office, Washington, D. C., who is the authorized agent of the Federal Government for the sale of all publications.

The Superintendent of Documents *is not an official of the Bureau of Mines.* His is an entirely separate office, and he should be addressed:

SUPERINTENDENT OF DOCUMENTS,
Government Printing Office,
Washington, D. C.

The general law under which publications are distributed prohibits the giving of more than one copy of a publication to one person. Additional copies must be purchased from the Superintendent of Documents. The price of this technical paper is 10 cents.

Second (revised) edition, March, 1914.

First edition issued in June, 1913.

CONTENTS.

Page.
Introduction 5
The flash point 5
The fire hazard 5
Investigations to determine flash points 6
  Work done in Great Britain 7
  Work done in the United States 7
    Principal testers used 7
    Comparison of the principal testers 8
Classification of testers 8
  Open-cup testers with water bath 8
  Open-cup testers with air baths and sand baths 8
  Semiclosed testers 9
  Closed testers 9
  Open testers with saturated vapor 9
  Closed testers with saturated vapor 10
  Closed vapor-pressure testers 10
Distillation tests 11
Factors to be considered in determining the flash point 11
  Manner of making tests 11
  Effect of atmospheric pressure 11
  Features of oil cup 12
  Features of thermometer 13
    Size of bulb 13
    Depth of immersion 13
    Correction for exposed portion of stem 13
  Rate of heating 14
  Effect of prolonged heating or cooling 14
  Importance of stirring the oil 15
  Size of test flame 15
  Distance of test flame above oil 15
  Comparison of gas, oil, and electric test flames 15
  Effect of duration of exposure of the test flame 15
  Effect of room temperature 16
  Burning point 16
  Effect of water 16
  Removal of water prior to testing 17
  The personal equation 17
Relation of flash point to density 18
Testers recommended by foreign governments and by the Government of the United States 18
Testing flash point of lamp oils with Bureau of Mines testers 18
  Selection of the workroom 18
  Selection and care of the sample 18
  Preliminary tests 19
  Filling and adjusting the tester and making the test 19

Original from PRINCETON UNIVERSITY

Page.
Burning point.......... 20
Substitute or secondary testers.......... 20
  The open-cup test.......... 20
  The test-tube tester.......... 20
Results of later tests.......... 21
  Standardization of instruments.......... 21
  Use of gas or oil ignition flames.......... 22
  Effect of stirrer on flash point.......... 23
  Effect of height of filling.......... 23
  Effect of overflow cup on flash point.......... 24
Summary.......... 25
Conclusion.......... 26
Convenient tables.......... 27
Specifications for the Bureau of Mines flash testers.......... 29
Bibliography.......... 31
Publications on petroleum technology.......... 38

ILLUSTRATIONS.

Page.
PLATE I. *A*, modified Pensky-Martens tester ready for use; *B*, modified Abel-Pensky tester ready for use.......... 16
II. Testers dismantled to show parts.......... 18

Original from PRINCETON UNIVERSITY

THE FLASH POINT OF OILS; METHODS AND APPARATUS FOR ITS DETERMINATION.

By Irving C. Allen and A. S. Crossfield.

INTRODUCTION.

In the handling of lamp oils, particularly in mines and in buildings where open lights are used, it is important that a relatively safe oil—that is, one with a high flash point—be employed. Equally important is the determination of the inflammability of all oils in common use. This paper, which is published by the Bureau of Mines in the interest of greater safety at mining and industrial plants, does not aim to establish definite flash points for oils but describes the instruments and methods of testing that can be used as a basis on which to establish such flash points. In connection with the discussion of the subject of this paper effort has been made to present a complete bibliography. The numbers in parentheses in the text refer to the books or articles as numbered in the bibliography (pp. 31 to 37).

THE FLASH POINT.

In the various methods used for determining the flash point of an oil the temperature at which its vapor flashes is not a definite factor but is dependent on a number of physical and chemical conditions not under the control of the operator. The flash point is not an indication of the value of an oil for any particular purpose. It is an indication only of the temperature at which the oil gives off vapors in such volume that they form an inflammable mixture with the air. If exposed to an electric spark or a flame, the mixture will ignite and the flame extend throughout the mixture; that is, the mixture of vapor and air is explosive. The flash point is of importance mainly in connection with fire hazards.

THE FIRE HAZARD.

The tendency of any substance, as an oil, to place any material in danger of loss or injury by fire is known to underwriters as the "fire hazard" of the substance. Attempts have been made to assign to this term a definite value in order that an equitable ratio of insurance rating may be levied on different substances. As yet, however, because of the factors involved, this has not been accomplished. The fire hazard of a substance is affected not by one but by many chemical and physical factors, such as the vapor pressure of the substance, the vapor density and diffusibility, the explosive limits of the vapor mixed with air, the calorific value of the substance, the corrosive action of the substance, and even such toxic properties of the substance, or its vapors, as might affect firemen trying to overcome a fire. All of these factors and others have a direct bearing on the fire hazard of an oil or inflammable substance, and it is desirable to assign to each factor a value as definite as possible.

Of all the fire-hazard factors of oils the flash point is perhaps the most important, because from the actual ignition of the substance the injury is usually developed. It is therefore exceedingly desirable in determining this factor to have methods that are uniform and may be duplicated.

No attempt is made in this paper to place a relative value on any one of the conditions determining a hazard, but the paper does describe attempts to establish definitely a method of determining a particular thing—the flash point—as one factor in the conditions governing the danger from fire.

A requirement that an oil shall have the highest practicable flash point, as such a requirement tends to reduce the fire hazard to a minimum, is praiseworthy and humane. But to require too high a flash point may, in the case of a lamp oil, impair the burning qualities of the oil and also work a hardship on the refiner. However, the immediate profits of the refiner should be deemed less important than the safety of the user and the protection of the public against possible loss of life and of property by fire (2).

The fire hazard of lubricating oils is of importance when the lubricants are used for rapidly running machinery, as in spinning mills or wood mills, or are used in factories containing combustibles and in compressors for air, ammonia, or other gases (3).

Particular attention should always be given to the handling, storage, and inspection of all inflammable liquids (6–9).

INVESTIGATIONS TO DETERMINE FLASH POINTS.

In the endeavor to ascertain the temperature at which an oil becomes dangerous many workers have experimented through a long series of years with numerous instruments and methods of testing, have developed many patterns of apparatus, and have ascertained some important facts regarding the determination of fire hazards.

The ordinances in the several States of the United States regarding the fire hazards of petroleum products, based solely on the flash points of the products, have been formulated independently of one another and seem to have little in common. The testers used are not comparable with each other as they embody different theoretical considerations, vary in dimensions and in construction (10, 11), and yield results that differ widely. This utter lack of uniformity works a hardship on the refiner and confuses the public.

WORK DONE IN GREAT BRITAIN.

As early as 1862 (12) the Government of Great Britain realized the importance of obtaining an instrument and a method of testing that would show the tendency of an oil to ignite, and in 1868 Sir Frederick Abel, Dr. Letheby, and Dr. J. Attfield were authorized to investigate the general matter of flash tests (13). This committee presented for consideration, but without definite specifications, the ordinary open-cup tester, which, however, because of its inaccuracies, did not meet with general acceptance. The subject continued to occupy the attention of Parliament from time to time until 1875, when Abel proposed an instrument that was almost identical with the present Abel-Pensky tester and has since then been considered the official tester of that Government (14).

WORK DONE IN THE UNITED STATES.

About this time—that is, between 1860 and 1880—the consideration of flash-point determination occupied the attention of the American public. Testers of various patterns were suggested and have been used independently by the numerous men interested, and many different testers are in use to-day in spite of their inaccuracies and the widely varying results obtained by them (15). C. D. Chamberlin, secretary and counselor general of the National Petroleum Association, stated in 1910 (16):

> Thirty-four of our forty-six States have laws providing for the inspection of petroleum and its products, and yet no two States have a law in common. This in itself forbids economy in manufacture; if a definite oil has to be manufactured to suit the requirements of each State there must necessarily be waste.

The situation has not materially changed since that time.

PRINCIPAL TESTERS USED.

The testers used in the United States are of many kinds and give different results. The seven best known testers are the Tagliabue open tester (17), the Tagliabue closed tester (18), the Elliot or New York State tester (19), the Foster tester (20), the Cleveland tester, the Abel-Pensky tester (21), and the Pensky-Martens tester (22). In addition an ordinary small open glass beaker or porcelain evaporating dish warmed over a flame or on a water or sand bath is still much used.

COMPARISON OF THE PRINCIPAL TESTERS.

The open-cup testers, as the Cleveland and the Tagliabue open cup, with lamp oils, give results about 5° C. above the flash point, and in the case of heavy lubricating oils the flash point may be 25° C. higher than the flash point determined with the Abel-Pensky or the Pensky-Martens testers. The Foster tester reads some 3° C. higher than the Tagliabue "closed tester." The Tagliabue "closed tester" reads some 8° C. higher than the Elliot tester, and 2 to 3° C. higher than the Abel-Pensky tester (23). For further comparisons see references 24 to 26 in the bibliography.

CLASSIFICATION OF TESTERS.

Testers may be grouped into six classes, namely: (1) Open-cup testers, (2) semiclosed testers, (3) closed testers, (4) open testers with saturated vapors, (5) vapor-pressure testers, and (6) distilling testers.

OPEN-CUP TESTERS WITH WATER BATH.

Albrecht (27), S. Aisinmann (27), J. Allen (28), Arnaboldi (29), J. Attfield (30), C. F. Chandler (31, 32), the inventor of the Cleveland tester, the Danes (33), Ehrenberg (34), C. Engler (35), C. Engler and R. Haass (36), H. Engler (37), Ernecke and Hannemann (38), E. Granier (39), H. Höfer (40), Hutton (41), the inventor of the Indiana State tester (42), E. Jacobsen (43), Kyll (44), Lenoir and Forster (45), the inventor of the Minnesota State tester (46), Möser (47), G. Saybolt (48), Squires (49), Tagliabue (17), R. Vette (50), H. N. Warren (51), V. Weise (52), and others experimented with a simple open cup about 5 centimeters in diameter and 7 centimeters in depth. The cup was half filled with the oil to be tested, and warmed on a water bath. From time to time a small lighted taper was exposed momentarily to the oil vapors. When the oil vapors ignited and showed a flash of flame the temperature of the oil was ascertained by a thermometer, the bulb of which had been previously immersed in the oil.

OPEN-CUP TESTERS WITH AIR BATHS AND SAND BATHS.

F. A. Courtois (53) worked with lamp oils in a manner similar to that used by other investigators, but warmed his oil cup on an air bath, whereas for lubricating oils R. Kissling (54), A. Künkler (55), J. Marcusson (56, 57), E. Stoeber (58), and Truemann (59), heated the oil in a small open porcelain dish or crucible fixed in a sand bath, and P. H. Walker (60) used a nickel crucible heated on an asbestos ring. W. Herbig (61) improved this open tester by covering the dish with a fire-clay tile provided with a small hole through which to introduce the test flame.

Digitized by Google Original from PRINCETON UNIVERSITY

In all of the open-cup testers the most volatile and inflammable of the vapors escape first, but not in sufficient quantity to be readily ignited. When the temperature reaches the point at which the vapors are given off in sufficient quantity for ignition, the temperature of the oil has risen above its lowest flash point or that temperature at which the accumulated vapors would have been inflammable in a closed vessel, the condition most closely resembling that of oil in the reservoir of a lamp or in an oil tank. The temperature of the oil in the open cup, therefore, is not the true flash point, but may be 5° to 25° C. too high (27). Also the vapors rising freely from the surface of the oil in an open cup, even in a carefully sheltered room, are exposed to air currents and drafts which seriously interfere with the test; furthermore, the operator may breathe on the surface of the oil, unless he take most scrupulous care to avoid doing so, and thus cause other variations in the accumulation of vapors, so that the apparent flash point he obtains will be too high. The combined errors may cause a variation of 1° to 25° C. in the determination of the flash point, depending on the substance tested (24). Moreover, the ignition flame must be applied in a precise manner to insure uniform results, and such application is not practicable in any of these open-cup testers.

SEMICLOSED TESTERS.

Various investigators improved the open-cup tester by adding a cover with a small opening through which the test flame was applied to the vapors or through which the vapors were allowed to escape past the burning taper. Among these investigators were O. Braun (62), C. F. Chandler (63), A. H. Elliot (19), C. Engler (64, 65), Foster (20), Heumann (66), Kuckla (67), Luchaire (68), Mann (69), Millspaugh (70), E. Parrish (71), the deviser of the Phlog-elaio-metre tester (72), J. Skalweit (73), Tagliabue (18), the deviser of the Wisconsin State tester (74), and others (75).

CLOSED TESTERS.

Although the semiclosed testers gave more uniform results, considerable variations were noted in determinations made by careful workers, and F. Abel (21, 76), Pensky-Martens (22), A. Bernstein (77), O. Braun (78), C. Engler (35, 79, 80), A. Gawalowski (81), Granier (82), J. Gray (83), J. A. Harker (84), D. Holde (85, 86), E. Jacobsen (87), T. W. Keates (88), Künkler (89), Letheby (90), Pease (91), G. Saybolt (92, 93), Schmitz (94), Sintenis (95), Vette (96), R. Weber (97), and H. F. Wiebe (98–100) worked with closed testers fitted with a small slide that opened and closed a small aperture through which the test flame could be applied at any desired instant.

OPEN TESTERS WITH SATURATED VAPORS.

Other workers, as F. F. Beilstein (101), L. Liebermann (102), A. Reythien and H. Hempel (103), and J. T. Stoddard (104, 105), determined the tendency of an oil to generate vapors by bubbling a current of air through the oil warmed on a water bath, allowing the mixture of oil vapor and air to pass a lighted taper at the opening of the oil cup and noting the temperature at which ignition occurred.

Although these workers claimed satisfactory results, the authors have found that results with this type of tester can be made to vary widely by changing the volume of the air current. With a slow stream of small air bubbles passing at the rate of about 0.1 c. c. per second into a 100-c. c. test tube containing 20 c. c. of oil, immersed in a well-stirred water bath, and with all precautions taken to correct the temperature readings, an oil that flashed in an Abel-Pensky tester at 44° C. flashed at a temperature above 50° C. On increasing the air current to a quantity sufficient to give a froth about 1 centimeter deep on the oil a flash point below 30° C. was observed. Because of this wide range in the results obtained, depending alone on the volume of air used for agitation and combustion, and because the particular volume of air must of necessity be fixed arbitrarily, it is believed that this method is not reliable for accurate testing.

CLOSED TESTERS WITH SATURATED VAPOR.

The method of Beilstein and others for generating the vapors was improved by R. Haass (106, 107), H. Hörler (108), and V. Meyer (109, 110), who warmed to a desired temperature a definite quantity of oil and air contained in a closed vessel on a water bath. The vessel was then agitated by vigorous shaking and replaced in the water bath. The froth and mist formed were allowed to settle until the oil had come to the temperature of the bath. The vessel was then removed, the vapors exposed to a flame or an electric spark, and the flash determined. This method insures the space above the oil being saturated with oil vapor, a condition not attained in any other tester, and not necessarily attained in the reservoir of a lamp.

The test, however, determines only whether the oil will or will not flash at a given temperature, and is valuable for this purpose only. But determination of the flash point of an oil requires repeated trials, which with this apparatus are time-consuming and hence not practicable. The flash points determined with this apparatus are some 9° C. (106) lower than those determined with the Abel-Pensky and Pensky-Martens testers.

CLOSED VAPOR-PRESSURE TESTERS.

In efforts to determine under what conditions oils become dangerous, K. W. Charitschkoff (111), Geissler (112), Meusel (113), Salleron and Urbain (114, 115), and P. H. Vanderweyde (116) endeavored to establish definite relations between fire hazard and the vapor pressures developed by oils contained in closed vessels. Their efforts were unsuccessful, as the fire hazard, though affected by the vapor pressure, is determined by other physical and chemical properties and by variable conditions as well (see pp. 5 and 6).

DISTILLATION TESTS.

D'A. de Barran (117), F. P. Beilstein (118), and T. Rosenbladt (119) endeavored, also without success, to establish a definite relation between the fire hazard and the quantity of vapors distilled between given temperatures. P. Dvorkovitz (120) maintains that the distillation test is the best criterion for the determination of the fire hazard of an oil, and states that a good safe oil can be obtained by allowing the finished refined oil to contain a proportion of light oils, of which not more than 10 per cent should distill below 150° C., and not more than 10 per cent should be left as residue after distillation at 300° C.

FACTORS TO BE CONSIDERED IN DETERMINING THE FLASH POINT.

The important points to be considered in the construction and manipulation of an instrument to determine the flash point of an oil may be stated as follows (84,121):

MANNER OF MAKING TESTS.

Tests should always be duplicated and should always be made with fresh samples of oil. The conditions under which the test vapors are generated should correspond as nearly as possible to the conditions found in practice. The quantity of oil should be such that no appreciable change in composition takes place during the test because of the generation and the consequent loss of the vapors or the lighter fractions from the body of the oil (35, 36, 122).

EFFECT OF ATMOSPHERIC PRESSURE.

Variations in atmospheric pressure have been observed to decidedly affect the flash point. A rise of 1 mm. in the barometer raises the flash point, according to different workers, by 0.03000° C. (123), 0.0437° C., and 0. 0350° C. (124), an average of 0.0362° C. A sudden change of barometric pressure, however, causes only a slow change in the flash point (125), because time is an important factor in the evolution of vapors from an oil. The flash point finally observed should be corrected for barometric pressure by applying the proper correction, as given in Table 1.

FEATURES OF OIL CUP.

The shape and size of the cup containing the oil and of the air space above the oil are important. As regards the size of the cup, the greater the surface of oil exposed the more rapid will be the evolution of the light and inflammable vapors at any given temperature, and consequently the lower will be the flash point (76).

The thickness of metal in the cup has significance. A heavy cup and cover will require more heat to warm them and will lengthen the time required for the test. The cup and cover of the German Abel-Pensky tester weighs about 143 grams, whereas that of the British Abel tester weighs about 76 grams. The German Abel-Pensky tester therefore gives a slightly retarded—that is, higher—result than the British Abel tester (10).

The distance of the surface of the oil below the rim of the cup should be definite and always the same. The test should always be made when the oil surface is on the mark and not above it (126). The usual practice is to fill the cup with cold oil to the mark in preparing for the test and to disregard the expansion of the oil during the subsequent warming.

A projecting point should be used as the mark for filling, as in the Abel-Pensky tester, and not a line, as in the Pensky-Martens tester. The surface of the oil can be read with reflected light at a point projecting 1 cm. from the side of the cup more accurately than at a line on the side of the cup, because the meniscus formed by the oil surface at the side of the cup will distort the reflected image and in obscure light will render precise reading difficult. Filling the cup 2 mm. above the mark in a Pensky-Martens tester may result in depressing the flash point 2.5° C. in the case of an oil that flashes at 150° C. (27), and as much as 7.5° C. with an oil that flashes at 300° C. A variation in filling of 6 mm. in a Pensky-Martens tester, according to D. Holde (127), makes a difference of 1 to 1.5° C. in the flash point. A. Martens states that an initial filling of 20 c. c. below the mark raises the flash point 1 to 2.5° C. (128), and a filling of 20 c. c. above the mark lowers the flash point 1 to 1.5° C.

The authors found that during a test a particular lamp oil, heated from room temperature (23° C.) to its flash point (46° C.), expanded a vertical distance of 0.5 mm., or 0.022 mm. per 1° C. A lubricating oil, heated from room temperature to its flash point (205° C.), expanded a vertical distance of 2.2 mm., or 0.012 mm. per 1° C. It is important, therefore, that the cup be always filled exactly to a definite point and that it be kept filled to this point during the entire time

Digitized by Google Original from PRINCETON UNIVERSITY

of the test. The testers used by the Bureau of Mines have been fitted with an annular overflow cup.

The dimensions of the air space between the cup and the bath are important. The greater the distance the slower will be the rise in temperature, because the slower will be the transmission of heat from the bath to the oil. The annular overflow cup supported on a fiber or rubber seat also prevents the oil around its upper and outer edge from being superheated, as happens in the Pensky-Martens cup.

The cup should be protected by the bath even to its upper rim, because it is as essential to control the temperature of the vapors as to control that of the oil itself, for the inflammability of the air-vapor mixture is affected by its temperature, and this temperature should be the same as that of the oil.

FEATURES OF THERMOMETER.

SIZE OF BULB.

The size of the thermometer bulb is of importance. Differences in dimensions may cause variations in thermometer readings of 0.5° C. (10). The official thermometer used in the British Abel tester gives a flash point 0.14° C. higher than does the thermometer of the German Abel-Pensky tester, principally because of the difference in size of bulb.

DEPTH OF IMMERSION.

Variations in the depth of immersion of the thermometer bulb are important. An elevation of 2.5 mm. in the depth of the bulb depresses the indicated flash point by 0.32° C. (84). With the bulb immersed to 38 mm. below the surface in an unstirred cup, F. C. Calvert (129) found the flash point of a certain oil to be 34.4° C., whereas with the bulb immersed 7 mm. the flash point was indicated as 36.7° C. The difference would have been inappreciable if the oil had been well stirred.

CORRECTION FOR EXPOSED PORTION OF STEM.

F. Mayer (130) found that the correction for the exposed portion of the stem of a thermometer which read to 500° C. and was from 265 to 300 mm. long might be as much as 3.3° C. at 150° C., 4.4° C. at 175° C., 5.8° C. at 200° C., 7.3° C. at 225° C., 9.0° C. at 250° C., 10.7° C. at 275° C., 12.6° C. at 300° C., 14.7° C. at 325° C., and 16.8° C. at 350° C. To estimate this error for any given thermometer he developed the following formula: $C = (t-tm)\ lf\ \left(\frac{500}{l}\right) 0.00018$, in which C = correction in degrees centigrade, t = temperature of the oil, tm = temperature of the middle of the exposed thermometer thread, lf = length in millimeters of the exposed thermometer thread,

l = length in millimeters of the scale of the thermometer, and
0.00018 = cubical coefficient of expansion of mercury.

The following formula to correct for the stem error may also be used: $C = KN\ (T - t)$ in which N = the number of degrees showing above the surface of the oil; T = the temperature of the oil, and t = the mean temperature of the emergent stem. The value of the constant K, the apparent expansion coefficient of mercury in glass, is for ordinary thermometer glass and Jena thermometer glass No. 16 0.000157; for Jena thermometer glass No. 59 0.000163; and for "verre dur" 0.000158. The correction is positive; that is, it is to be added to the thermometer reading.

As it is difficult to apply either of the above formulas, the thermometers before use should be calibrated when immersed in the bath to the proper depth; that is, to the metal collar as shown in Plate I, and when conditions correspond as nearly as possible to the conditions of testing.[a]

RATE OF HEATING.

The heating should be slow and regular so that the vapors are evolved just fast enough to maintain equilibrium between the liquid and gaseous phases at a slowly increasing temperature (84, 131). It is believed that the rate of heating should be between 2° and 3° C. per minute (103), as this rate will insure good equilibrium between the two phases.

The heating and testing should begin at a temperature at least 10° C. below the flash point, as determined by a preliminary test, in order to give time for equilibrium to be established before the flash point is reached. F. C. Calvert (129) found the flash point of a particular oil to be 34.4° C. when the oil was heated from room temperature to the flash point in 15 minutes, 36.7° C. when the oil was heated to the flash point in 20 minutes, and 39.4° C. when this heating took 30 minutes. He found that if the testing was begun at 7° C. below the flash point, instead of at 10° as stated above, the flash point was raised about 1° C.

EFFECT OF PROLONGED HEATING OR COOLING.

Heating of the oil for a number of minutes prior to testing causes a lowering of the flash point because of the loss of the lightest vapors (125).

On the other hand, cooling of the oil for a number of minutes just prior to testing lowers the flash point because of the condensation and accumulation of these light vapors (132), but if the slide of the tester be left open for some minutes just prior to testing, the cooling has less effect.

---

[a] Calibration of thermometers and verification of the dimensions and accuracy of operation of testers will be made by the Bureau of Standards at Washington, D. C.

IMPORTANCE OF STIRRING THE OIL.

The differences of temperature at different points within the oil in the ordinary unstirred cup may be as much as 3° to 5° C. (84). The oil is hottest along the bottom and sides of the cup. The heated oil rises to the surface along the sides, then flows toward and down the center. It may be 2° to 3° C. hotter than the vapors above it. Therefore the oil and vapors must be thoroughly stirred during the test. For this reason the Abel-Pensky tester for lamp oils that is used by the Bureau of Mines is provided with a stirrer similar to that used in the Pensky-Martens tester for lubricating oils. The renewing of the surface when evaporation takes place is also important.

SIZE OF TEST FLAME.

The size of the test flame is important. A test flame the size of the ivory bead on the cover of the Abel-Pensky tester burns about 0.1 cubic foot of coal gas per hour. A test flame of half this size raises the flash point 1° C., and a test flame of one and a half times this size lowers the flash point 0.5° C. A variation of 20 per cent in the size of the flame causes an inverse variation of 0.3° C. in the flash point (84).

DISTANCE OF TEST FLAME ABOVE OIL.

The distance of the test flame above the oil surface is important. The test flame should be at a definite and constant distance above the surface of the oil, as the distance affects the temperature of the bath, the vapors, and the oil. The farther the test flame is from the surface of the oil, the later the flash and the higher the flash point determined. The test flame should not be brought too near to the oil nor should the exposure be too long, for local heating will result and will cause an error in the reading.

COMPARISON OF GAS, OIL, AND ELECTRIC TEST FLAMES.

A coal-gas test flame gives a flash point 0.3° C. lower than does an oil test flame. An electric test spark gives a variable but usually a lower result than does a gas flame. Because it is not possible to control the intensity and duration of the electric spark and because variations in the intensity and duration of the spark give variable results, the electric test spark is not suitable for an official instrument.

EFFECT OF DURATION OF EXPOSURE OF THE TEST FLAME.

The duration of the exposure of the oil vapors to the test flame is important. Frequent opening of the aperture in order to expose the test flame permits frequent escape of the vapors and consequently retards flashing and raises the flash point. Exposing the test flame at each 0.5° C. rise in temperature, as recommended with the German Abel-Pensky tester, gives a flash point 0.14° C. higher than that obtained by exposing the flame at each 1° F. rise in temperature, as is recommended with the British Abel tester (84).

The testing or exposure of the test flame should begin at least 5° C. below the true flash point after correction has been made for barometric pressure.

EFFECT OF ROOM TEMPERATURE.

Allowing the oil to stand exposed for a number of hours in a warm room materially lowers the flash point. Abel (133) found that a lamp oil that ordinarily flashed at 22.8° C. flashed at 18.9° C. when the laboratory was at a tropical temperature (30° C. to 40° C.). In a hot climate or on a hot day the collected vapors should be removed with an aspirator, or one should gently blow over the surface of the cup before putting on the cover in order to obtain results comparable with those obtained with the same oil in a temperate climate or on a cool day. This procedure, however, is not entirely satisfactory, as results obtained by different operators are not uniform. A more satisfactory way is to begin the testing at a temperature some 10° C. below that required in a temperate climate in order to remove the accumulated vapors. This procedure causes the loss of some of the lighter constituents, but such loss is unavoidable, particularly in tropical climates or on hot days or after the oil has stood for a number of hours in a warm room. Concordant results can be obtained in this way.

The legally established flash point for an oil to be used in the Tropics should be somewhat lower than that for the same oil for similar use in a temperate climate.

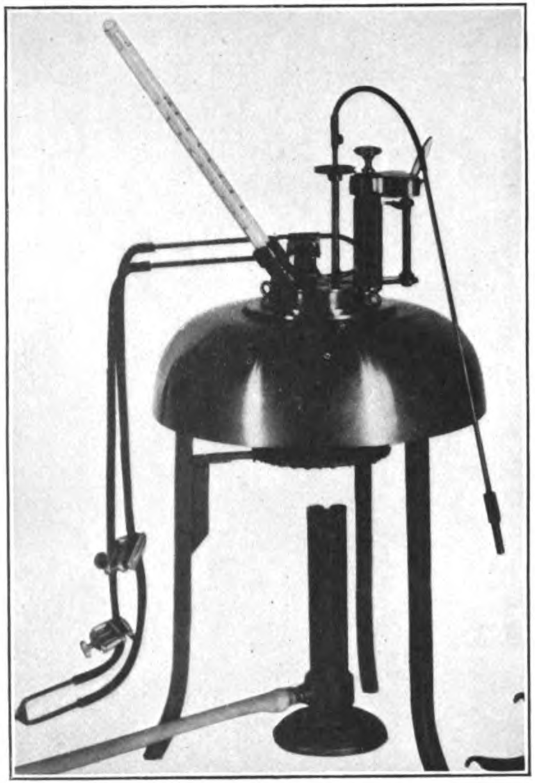
BURNING POINT.

The burning point, or that temperature at which the oil ignites and continues to burn in an open cup, is of significance. If the oil is a normal refined fraction of petroleum the burning point will be 2° to 11° C. higher than the flash point (134). The difference will be considerably greater, however, if the oil be a mixture of a light and a heavy oil. In the case of a refined oil, however, the higher the flash point the smaller will be this difference (135).

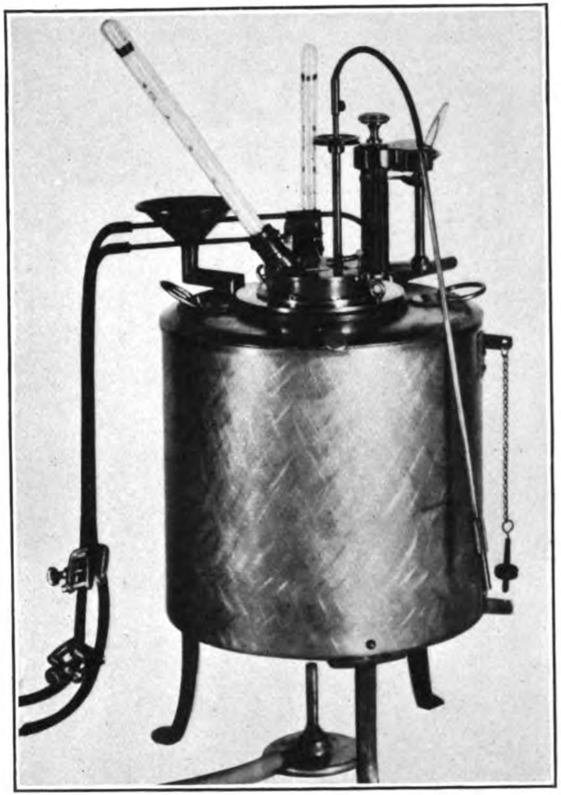
EFFECT OF WATER.

The presence of small proportions of water in heavy oils makes the determination of their flash points uncertain, and 1 per cent will prevent flashing entirely (138, 139), or at least will delay the flash until after the water has been distilled from the oil. Matuschek (140) found that 0.1 gram of water in the cup of oil raised the flash point 1° to 2° C., and that 0.7 gram of water raised the flash point about 9° C.

Original from PRINCETON UNIVERSITY



A. MODIFIED PENSKY-MARTENS TESTER, READY FOR TEST.



B. MODIFIED ABEL-PENSKY TESTER, READY FOR TEST.

Water also causes frothing of the oil. If an oil that flashes above 80° C. contains 0.2 per cent of water, only the approximate flash can be obtained, and then only in an open-cup tester with cautious heating and close attention to prevent boiling over.

REMOVAL OF WATER PRIOR TO TESTING.

Finely divided water in mineral oils is difficult to remove by settling or by heating without causing injury to the oil. Warming in any way or distilling to remove the water seriously lowers the flash point and should be avoided; diluting with a lighter solvent introduces a low-flashing oil that will entirely mask the flash point of the oil being tested. The water is best removed by treatment in an electric separator (141). A convenient method of reducing the water content of an emulsified oil has been developed by F. G. Cottrell, J. B. Speed, and A. C. Wright. The method is admirably adapted to reducing the water content on a large scale. A convenient apparatus for the laboratory may be made as follows:

A glass tube, about 5 cm. in diameter, 30 cm. long, and open at the top, is drawn out at its lower end and fitted with a glass cock. On the inner surface of the tube is fitted a copper-gauze cylinder, extending from the top to 5 cm. from the bottom. Between the gauze and the tube is placed a single wrapping of wet cheesecloth or very thin muslin. The tube, held in a vertical position, has centered within it a heavy copper wire or rod, extending from the top to 5 cm. from the bottom. The copper wire and the copper-gauze cylinder are connected, by means of leads and a switch, directly to the terminals of a high-potential (2,200-volt) step-up transformer.

The tube is filled with the emulsified oil to be examined, and the circuit is closed. The high-tension current breaks down the emulsion, the water is drawn to the wet-cloth surface, trickles down the cheesecloth, and settles in the lower end of the tube, whence it can be drawn off. With oils containing considerable water, the current must be broken at short intervals to prevent overheating of the oil. With all oils, frequent breaking of the current is advisable.

This process readily reduces the water content of an emulsion, with little heating, to a very small proportion and is admirably adapted to reducing the water content of emulsions when heating is objectionable.

THE PERSONAL EQUATION.

In general testing, so far as is possible, the effect of the personality of the operator should be eliminated and the manipulation of the tester made entirely mechanical and automatic (142). The most accurate tester and the tester that most nearly reproduces actual working conditions should be adopted for official tests.

RELATION OF FLASH POINT TO DENSITY.

There is no definite relation between the flash point and the density of an oil (136, 137) as a very small proportion of light oil, not enough appreciably to affect the density, will materially lower the flash point.

TESTERS RECOMMENDED BY FOREIGN GOVERNMENTS AND BY THE GOVERNMENT OF THE UNITED STATES.

The testers that most nearly meet all the conditions that have been described are the closed Abel-Pensky tester, with stirrer, overflow cup, water bath or oil bath, and mechanical exposure of the test flame for exactly one second, fitted with standardized thermometers for oils flashing up to 60° C. (143); the same tester with a bath of petroleum cylinder oil or palmine oil having a flash point of about 250° C. for oils flashing between 60° C. and 110° C.; and the Pensky-Martens tester, with air bath, for oils flashing above 110° C.

The general adoption of these two testers, of like dimensions and, except their baths, of like construction, in the United States for all interstate and foreign trade seems advisable, because they are already well known in the United States and are the recognized official instruments in Austria-Hungary, Belgium, Denmark, France, Germany, Great Britain, Holland, Italy, Japan, Norway, Roumania, Russia, and Sweden.

The appearance of the Bureau of Mines testers is shown in Plates I and II.[a] Certain of the parts shown in Plate II have been numbered for reference, as follows: *1*, water-bath container; *2*, jacket; *3*, base leg; *4*, base ring; *5*, air-bath device; *6*, jacket; *7*, gauze frame and gauze; *8*, cup lifter; *9*, cover lifter; *10*, oil cup; *11*, oil-cup cover; *12*, overflow cover; *13*, stirrer; *14*, stirrer shaft; *15*, stirrer sheave; *16*, clock mechanism; *17*, thermometers.

TESTING FLASH POINT OF LAMP OILS WITH BUREAU OF MINES TESTER.

SELECTION OF THE WORKROOM.

The selection of a suitable workroom is very important. In testing lamp oils it is desirable to carry on the tests in a room with a temperature ranging from 18° to 20° C., and it is essential that the tester used be well protected from all interfering air currents. The illumination of the room should not be too bright, as the test flame and the flash are better observed in a dim light.

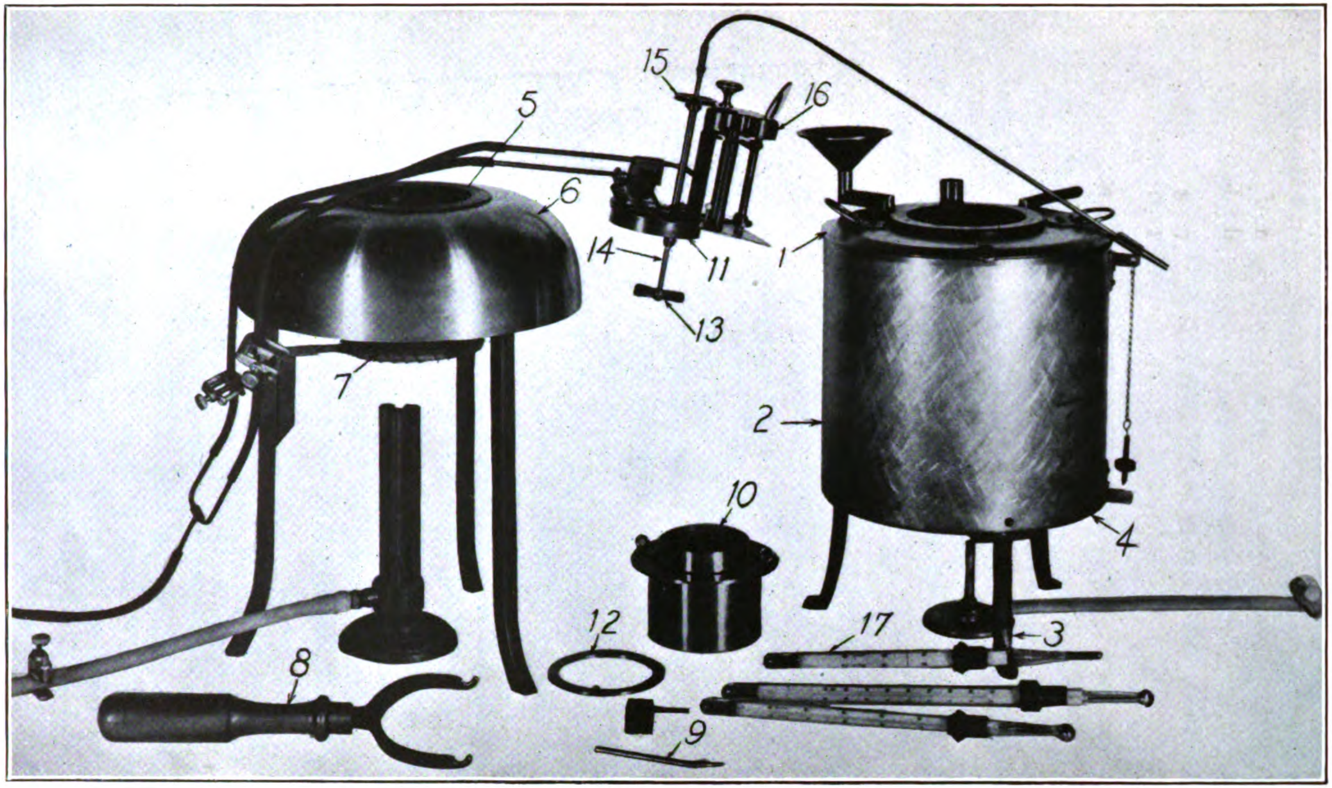
SELECTION AND CARE OF THE SAMPLE.

The proper selection and care of the sample are essential. In the selection of a sample for testing one must always be sure that the sample truly represents the oil to be tested. The oil should be

---

[a] Working drawings showing the construction of these testers, as modified by the Bureau of Mines, may be obtained on application to the Director of the Bureau of Mines.

Digitized by Google Original from PRINCETON UNIVERSITY



TESTERS DISMANTLED TO SHOW PARTS.

thoroughly mixed or the sample should be taken by the aid of a sampling tube from points symmetrically distributed throughout the body of the oil (144). The sample should then be kept hermetically sealed, or at least kept in a well-closed vessel in a cool place until ready for use. The sample should stand undisturbed in the workroom for such a time before testing that its temperature becomes practically that of the room.

PRELIMINARY TESTS.

The approximate flash point of an oil to be tested should be first ascertained by a preliminary test by heating the sample so that the temperature will rise at the rate of 1° C. per minute and applying the test after each 5° rise until the halo appears, and then at each 1° rise until the flash occurs. The test should be carefully repeated, in the following manner:

FILLING AND ADJUSTING THE TESTER AND MAKING THE TEST.

The sample and the oil cup must first be brought to a temperature of at least 10° C. below the approximate flash point of the oil, by standing the cup in an ice mixture if necessary, before the cup is adjusted in the bath. The lower edge of the overflow aperture is greased on its outer side to induce ready overflow when the oil expands. The clean, dry cup is then placed in the bath, the sample is run into the cup with the aid of a glass pipette until the filling point just disappears under the surface as seen by light reflected from the surface of the oil. Care must be taken not to splash the oil to the sides of the cup and not to have froth formed on the oil. All bubbles on the surface of the oil must be pricked with a heated wire. In case too much oil has been accidentally run into the cup, the cup must be emptied, washed clean with a good solvent, wiped dry, and a fresh filling made. After the filling has been correctly done, adjust the cover and thermometer immediately, light the test flame, and adjust it to the size of the ivory bead on the cover; that is, so that it will burn 0.1 cubic foot of coal gas per hour.

Allow the apparatus to stand 10 minutes, to give time for the oil vapors to accumulate, meanwhile stirring regularly and constantly at one revolution per second. Then light the gas flame below the bath and adjust to such a height, as determined by preliminary tests, that the temperature of the oil will rise at the rate of about 1° per minute. Warm to within 5° C. of the predetermined flash point and expose the test flame for exactly one second by means of the mechanism provided on the cover. Continue stirring and making the exposure at each 0.5° C. rise in the temperature until the flash occurs. Particular care must be taken that the cup is not subjected to drafts during the test and that the breathing of the operator is not allowed to interfere, particularly at the moment the test flame is exposed to the vapors. It will be noted that when the oil is about 5° C. below the flash point, the test flame, as it is exposed to the vapors, will be surrounded by a pale-blue halo, which gradually increases in intensity until a sudden inflammation, or gentle explosion, of the vapors or the "flash" occurs. The temperature at which this occurs, as registered by the thermometer in the oil, is the flash point. With fuel-oil residues or with poorly refined oils from which a small quantity of low-flashing fractions is continually being liberated, this halo may first appear at a temperature as much as 30° C. below the flash point.

The test should always be repeated with a fresh sample. The first sample should be thrown away, the cup washed with gasoline, wiped dry, the cup and water bath cooled to the proper temperature, and the test repeated exactly as described above. Duplicate tests should agree within 0.5° C. The mean of the two readings, if good agreement is noted, corrected for barometric pressure (see Table 1), is considered the flash point of the oil.

BURNING POINT.

The burning point is that temperature at which the oil ignites and continues to burn. To determine the burning point, open the cover, continue the heating, and expose the test flame to the vapors in the same manner as when taking the flash point, until the oil ignites and continues to burn.

SUBSTITUTE OR SECONDARY TESTERS.

It may happen that the cost of Bureau of Mines testers prohibits their use. In such an event, or when a high degree of accuracy is not required—that is, when the flash point of the oil is not within 5° C. of the minimum legal flash point—the flash point may be determined by means of an open-cup tester or a test-tube tester. But whenever it is necessary to know the flash point of the oil within 5° C. of the legal flash point, and in all cases of controversy or doubt, a precise instrument must be used.

THE OPEN-CUP TEST.

The open-cup tester is used in testing for approximate flash points only. A simple open-cup tester (see p. 8) that may be used for such testing is as follows:

A glass beaker or metal cup of the same dimensions as the Bureau of Mines testers—that is, 5.1 cm. in diameter and 5.6 cm. in depth—is filled to within 1.8 cm. of its upper rim with the oil to be tested. In testing lamp oils the cup is supported in a water bath by a flange at its upper edge, and in testing oils with higher flash points the cup is supported on a sand bath. A thermometer is supported with its

Digitized by Google Original from PRINCETON UNIVERSITY

bulb immersed in the oil. A test-flame burner is made by drawing a piece of hard glass tubing to a capillary about 1 mm. in diameter, to which gas is supplied. The flame is adjusted to 3-mm. cross section. If such a burner has not been prepared, a small wax taper, a burning string, or a splinter of wood may be used. The bath is heated with an ordinary Bunsen burner. The method of testing is as nearly as possible like that in official tests with the Bureau of Mines testers.

THE TEST-TUBE TESTER.

A simple and inexpensive tester, based on the principle developed by Meyer, Haass, and others (106 to 110), which will show whether a lamp oil will flash at any given temperature, and may be used in ordinary work, is made as follows:

A glass test tube approximately 2 cm. in diameter and 15 cm. long is one-quarter filled with the oil to be tested. The tube is loosely closed with a cork and is immersed to the cork in a water bath warmed to the desired temperature until the temperature of the oil has reached the temperature of the bath. The tube is then removed from the water bath and vigorously shaken. The tube is again immersed in the bath for a moment to equalize the temperature and to allow the spray to settle. The tube is then removed from the bath, the cork withdrawn in the immediate vicinity of a flame, and the vapors exposed for ignition. Failure of a flash or burning will denote that the oil will not flash at this particular temperature. If that temperature is the legal minimum flash point the oil will have satisfactorily withstood the test. If the test is carefully made, and concordant results are obtained on repetition, it may be trusted for ordinary testing.

RESULTS OF LATER TESTS.

Some additional data, obtained from tests made after the first edition of this paper was issued, are given in the following pages. In making the tests a degree of accuracy greater than 0.5° C. for oils flashing below 100° C. and 1° C. for oils flashing above 100° C. was not attempted, and any fractions of degrees reported in subsequent tables are derived as averages of several tests or from thermometer, barometer, or instrument corrections.

STANDARDIZATION OF INSTRUMENTS.

To obtain comparable results the two Bureau of Mines instruments used in the tests—a modified Abel-Pensky tester and a modified Pensky-Martens tester—were compared with an Abel-Pensky tester that had been standardized in 1908 by the Physikalische-Technische Reichsanstalt (certificate No. S. & R. 3114). Determinations of flash points of three different oils were made with the three instruments. The averages of the results of five tests agreeing within 0.5° C. are as follows:

Results obtained with Bureau of Mines testers compared with results obtained with standardized Abel-Pensky tester.

Designation of sample.	Flash point,[a] Abel-Pensky tester.	Flash point,[a] Bureau of Mines modified Abel-Pensky tester.	Difference.	Flash point,[a] Bureau of Mines modified Pensky-Martens tester.	Difference.
	° *C.*	° *C.*	° *C.*	° *C.*	° *C.*
X	47.3	48.0	+0.7	49.0	+1.7
No. 1086	36.3	37.0	+0.7	37.8	+1.5
No. 1087	44.5	45.5	+1.0	46.2	+1.7
Average	....	....	+0.8	....	+1.6

[a] Results represent averages of five tests.

In all results hereafter reported the corrections indicated as being necessary as a result of the tests have been made. The large corrections involved show that it is advisable to have all instruments intended for exact work compared with some established standard.

USE OF GAS OR OIL IGNITION FLAMES.

The use of gas or oil test flames is optional. In comparative tests natural gas, colza oil, and lard oil were used as ignition flames, with the Bureau of Mines modification of the Abel-Pensky tester. Between the three there was a maximum difference of 0.3° C., which is well within the error of manipulation. The results obtained were as follows:

Comparison of flash points obtained with gas and with oil test flames.

Designation of sample.	Flash point.		
	Gas test flame.	Lard-oil test flame.	Colza-oil test flame.
	° *C.*	° *C.*	° *C.*
No. 1087	45.5	45.4	45.2
Kerosene X	48.0	48.1	47.7

A petroleum distillate, "300° burning oil," on the other hand, gave a flash point approximately 0.8° C. too high; hence the use of such an oil as an ignition flame is not recommended. The difference is probably explained by the fact that the distillate flame was rather difficult to regulate, owing to the rapid flow of oil through the wick and owing to incomplete combustion, as indicated by a bright, luminous flame, which in itself may have obscured the first flash. Because of the ease of manipulation, a gas flame is most desirable.

EFFECT OF STIRRER ON FLASH POINT.

The heat is applied to the oil from the bottom and sides of the cup, with the result that convection currents start within the oil, their general direction being across the bottom of the cup, up the sides, across the top, and down the center past the thermometer bulb. Consequently the oil passing the thermometer is slightly cooler than that at the circumference of the surface, and a flash point lower than the true one is recorded. This is clearly shown in the results given in the following table:

Comparative flash points of stirred and unstirred oil samples.

Designation of sample.	Flash point.[a]					
	Bureau of Mines modified Pensky-Martens tester.		Bureau of Mines modified Abel-Pensky tester.		Pensky-Martens tester.	
	Oil stirred.	Oil unstirred.	Oil stirred.	Oil unstirred.	Oil stirred.	Oil unstirred.
	° C.	° C.	° C.	° C.	° C.	° C.
Kerosene X	....	....	....	....	46.2	45.7
1086	....	....	37.0	37.1	35.6	35.1
1087	46.2	45.4	45.5	45.2	44.3	45.8
1092	117.0	115.1	....	....	....	....
1095	184.7	183.0	....	....	....	....
1096	196.4	195.6	....	....	....	....

[a] Results given are averages of three tests each.

Further, the greater the rate of heating the greater will be the convection currents, and consequently the greater will be the difference between the temperature of the oil at the circumference and the temperature at the center of the cup. Also, the higher the flash point the greater will be the temperature differences. The differences are almost entirely removed by the use of a stirrer, and it has also been found easier to get concordant results in a stirred cup than in one that is without a stirrer.

EFFECT OF HEIGHT OF FILLING.

Different investigators have found that a definite filling of the cup has a decided effect on the determination of the flash point. Filling the cup above the point used as the filling mark lowers the flash point, because, obviously, the oil expands in heating and its surface is brought nearer the test flame. Expansion of the oil reduces the volume of the gas mixture, an explosive mixture is formed at a lower temperature, and consequently a lower flash point is recorded. An explosive mixture would be obtained at a lower temperature from a fixed weight of oil than from a fixed volume, and a lower flash point would result.

To do away with these sources of error the modified testers have been fitted with overflow cups so that as the oil heats and expands, the excess runs off, and the volumes of both oil and vapor mixture are kept constant. The above assumptions are substantiated by the results of tests given below:

Comparison of flash point obtained with constant weight and flash point obtained with constant volume.

[Instrument used, Bureau of Mines modified Pensky-Martens tester.]

Number of sample.	Flash point.[a]		Difference.
	Constant volume.	Constant weight.	
	°C.	°C.	°C.
1087	46.2	45.8	0.4
1092	117.0	115.1	1.9
1095	184.7	183.0	1.7
1096	196.4	195.3	1.3

[a] Results given are averages of three tests each.

EFFECT OF OVERFLOW CUP ON FLASH POINT.

The suggestion has been made that the overflow oil in the outer cup will be much hotter than the temperature indicated by the thermometer within the cup, and that the vapors liberated will pass back into the cup and give a flash below the true flash point of the oil, but it is believed that such conditions do not exist. In the first place, the cup is so constructed that the bottom is directly exposed to the hot bath and the oil in the cup, if stirred, is at a temperature not appreciably lower than that in the overflow cup. The volume of the oil that overflows is small as compared with that of the oil in the cup; and the quantity of vapors liberated from such a small volume, even at a slightly higher temperature, would have little effect on the flash point, particularly that fraction of the small volume that might pass back into the cup. Also, it is hardly to be assumed that the vapors would pass back into the cup rather than escape around the loosely fitting ring of the overflow cup. These views are substantiated by the fact that for no oil tested was a lower flash point determined in the cup with the overflow open than in the cup with the overflow plugged. As further proof, comparisons were made of the flash point obtained from an oil in the usual way with the flash point obtained from the oil after some low-flashing oil had been placed in the overflow cup. The results were as follows:

Effect of placing some low-flashing oil in the overflow cup.

[Instrument used, Bureau of Mines modified Abel-Pensky tester.]

Number of test.	Flash point of—	
	Oil 1087.	Oil 1087 with 5 c.c. of oil 1086 (flash point 37° C.) in the overflow cup.
	° *C.*	° *C.*
1	45.4	45.4
2	45.3	45.4
3	45.8	45.4
Average	45.5	45.4

As previously pointed out, the annular overflow cup surrounding the oil cup will also prevent superheating and consequent volatilization of the oil around the cup's upper outer edge.

SUMMARY.

The Bureau of Mines testers, modifications of the older forms of the Abel-Pensky and Pensky-Martens testers, have the following features: Each cup is fitted with an annular overflow cup into which, through a small opening on a level with the filling point, the excess of oil caused by expansion on heating flows. This arrangement assures constant volume of both the oil and the vapor mixture above the oil. The modified Abel-Pensky tester is provided with a paddle-wheel stirrer identical with that of the Pensky-Martens tester, and the automatic slide of the Abel-Pensky tester has been fitted to the modified Pensky-Martens tester. However, the last change necessitated raising the clockwork on insulating posts above the hot bath, as the intense heat drew the temper of the spring. The two testers recommended are therefore identical except for a water bath being used for testing low-flashing oils and a metal air bath for high-flashing oils. The cups, the automatic opening devices, and the stirrers of the two testers are interchangeable. Investigations conducted in the Bureau of Mines laboratories indicate that the tester for oils having a high flash point can be used satisfactorily for the testing of low-flashing oils, though the temperature regulation is not as exact as with the water-jacketed tester. The same conclusion has been reached by other investigators (99). Each tester is fitted with gas or oil ignition burners.

The important factors to be considered in the construction and manipulation of an instrument for determining the flash point of an oil may be stated as follows:

1. The conditions under which the test vapors are generated should be as like as possible for the conditions found in practice.
2. Corrections should be made for variations from the normal barometric pressure.
3. The shape and dimensions of the cup should be definite.
4. The size, shape, depth of immersion, and exposed part of the thermometer should be definite and the thermometer should always be calibrated. The thermometer should be calibrated when immersed to the collar, 60 mm. from its lower end.
5. The oil should never be exposed for any length of time at temperatures greatly higher or lower than the normal temperature.
6. The rate of heating on testing should be constant and at a rate of about 1° C. per minute for lamp oils and 3° to 5° C. per minute for oils with a high flash point.
7. The oil being tested should be uniformly stirred during the test.
8. The test flame should be of definite size; it should be exposed at a fixed distance above the surface of the oil and for a definite length of time.
9. All water should be removed from the oil prior to testing.
10. In general testing, so far as possible, the personal equation of operators should be eliminated and the manipulation of the tester made entirely mechanical and automatic.

CONCLUSION.

The most accurate tester and the tester that most nearly reproduces actual working conditions should be adopted for official tests. If all of the above factors be considered, it is believed that these two testers, the Abel-Pensky and the Pensky-Martens, as modified by the Bureau of Mines, most nearly meet the desired conditions.

The Bureau of Mines flash testers have been officially adopted by the National Fire Protection Association and the Independent Petroleum Marketers' Association of the United States, and are now being considered for adoption by committees on tests of the National Petroleum Association, the American Chemical Society, the American Society for Testing Materials, the International Petroleum Commission, and the American Petroleum Society.

CONVENIENT TABLES.

TABLE 1.—*Correction of flash point for normal barometric pressures.*

[Reading of barometer, mm.] [a]

Flash point, °C.														
760	650	655	660	665	670	675	680	685	690	695	700	705	710	715
19.0	15.5	15.6	15.7	15.8	15.9	16.1	16.2	16.4	16.6	16.7	16.9	17.1	17.3	17.4
19.5	16.0	16.1	16.2	16.3	16.4	16.6	16.7	16.9	17.1	17.2	17.4	17.6	17.8	17.9
20.0	16.5	16.6	16.7	16.8	16.9	17.1	17.2	17.4	17.6	17.7	17.9	18.1	18.3	18.4
20.5	17.0	17.1	17.2	17.3	17.4	17.6	17.7	17.9	18.1	18.2	18.4	18.6	18.8	18.9
21.0	17.5	17.6	17.7	17.8	17.9	18.1	18.2	18.4	18.6	18.7	18.9	19.1	19.3	19.4
21.5	18.0	18.1	18.2	18.3	18.4	18.6	18.7	18.9	19.1	19.2	19.4	19.6	19.8	19.9
22.0	18.5	18.6	18.7	18.8	18.9	19.1	19.2	19.4	19.6	19.7	19.9	20.1	20.3	20.4
22.5	19.0	19.1	19.2	19.3	19.4	19.6	19.7	19.9	20.1	20.2	20.4	20.6	20.8	20.9
23.0	19.5	19.6	19.7	19.8	19.9	20.1	20.2	20.4	20.6	20.7	20.9	21.1	21.3	21.4
23.5	20.0	20.1	20.2	20.3	20.4	20.6	20.7	20.9	21.1	21.2	21.4	21.6	21.8	21.9
24.0	20.5	20.6	20.7	20.8	20.9	21.1	21.2	21.4	21.6	21.7	21.9	22.1	22.3	22.4
24.5	21.0	21.1	21.2	21.3	21.4	21.6	21.7	21.9	22.1	22.2	22.4	22.6	22.8	22.9
25.0	21.5	21.6	21.7	21.8	21.9	22.1	22.2	22.4	22.6	22.7	22.9	23.1	23.3	23.4
25.5	22.0	22.1	22.2	22.3	22.4	22.6	22.7	22.9	23.1	23.2	23.4	23.6	23.8	23.9
26.0	22.5	22.6	22.7	22.8	22.9	23.1	23.2	23.4	23.6	23.7	23.9	24.1	24.3	24.4
26.5	23.0	23.1	23.2	23.3	23.4	23.6	23.7	23.9	24.1	24.2	24.4	24.6	24.8	24.9
27.0	23.5	23.6	23.7	23.8	23.9	24.1	24.2	24.4	24.6	24.7	24.9	25.1	25.3	25.4
27.5	24.0	24.1	24.2	24.3	24.4	24.6	24.7	24.9	25.1	25.2	25.4	25.6	25.8	25.9
28.0	24.5	24.6	24.7	24.8	24.9	25.1	25.2	25.4	25.6	25.7	25.9	26.1	26.3	26.4
28.5	25.0	25.1	25.2	25.3	25.4	25.6	25.7	25.9	26.1	26.2	26.4	26.6	26.8	26.9
29.0	25.5	25.6	25.7	25.8	25.9	26.1	26.2	26.4	26.6	26.7	26.9	27.1	27.3	27.4
29.5	26.0	26.1	26.2	26.3	26.4	26.6	26.7	26.9	27.1	27.2	27.4	27.6	27.8	27.9
30.0	26.5	26.6	26.7	26.8	26.9	27.1	27.2	27.4	27.6	27.7	27.9	28.1	28.3	28.4
30.5	27.0	27.1	27.2	27.3	27.4	27.6	27.7	27.9	28.1	28.2	28.4	28.6	28.8	28.9
31.0	27.5	27.6	27.7	27.8	27.9	28.1	28.2	28.4	28.6	28.7	28.9	29.1	29.3	29.4
31.5	28.0	28.1	28.2	28.3	28.4	28.6	28.7	28.9	29.1	29.2	29.4	29.6	29.8	29.9
32.0	28.5	28.6	28.7	28.8	28.9	29.1	29.2	29.4	29.6	29.7	29.9	30.1	30.3	30.4
32.5	29.0	29.1	29.2	29.3	29.4	29.6	29.7	29.9	30.1	30.2	30.4	30.6	30.8	30.9
33.0	29.5	29.6	29.7	29.8	29.9	30.1	30.2	30.4	30.6	30.7	30.9	31.1	31.3	31.4
33.5	30.0	30.1	30.2	30.3	30.4	30.6	30.7	30.9	31.1	31.2	31.4	31.6	31.8	31.9
34.0	30.5	30.6	30.7	30.8	30.9	31.1	31.2	31.4	31.6	31.7	31.9	32.1	32.3	32.4
34.5	31.0	31.1	31.2	31.3	31.4	31.6	31.7	31.9	32.1	32.2	32.4	32.6	32.8	32.9
35.0	31.5	31.6	31.7	31.8	31.9	32.1	32.2	32.4	32.6	32.7	32.9	33.1	33.3	33.4

Flash point, °C.													
720	725	730	735	740	745	750	755	**760**	765	770	775	780	785
17.6	17.8	18.0	18.1	18.3	18.5	18.7	18.8	**19.0**	19.2	19.4	19.5	19.7	19.9
18.1	18.3	18.5	18.6	18.8	19.0	19.2	19.3	**19.5**	19.7	19.9	20.0	20.2	20.4
18.6	18.8	19.0	19.1	19.3	19.5	19.7	19.8	**20.0**	20.2	20.4	20.5	20.7	20.9
19.1	19.3	19.5	19.6	19.8	20.0	20.2	20.3	**20.5**	20.7	20.9	21.0	21.2	21.4
19.6	19.8	20.0	20.1	20.3	20.5	20.7	20.8	**21.0**	21.2	21.4	21.5	21.7	21.9
20.1	20.3	20.5	20.6	20.8	21.0	21.2	21.3	**21.5**	21.7	21.9	22.0	22.2	22.4
20.6	20.8	21.0	21.1	21.3	21.5	21.7	21.8	**22.0**	22.2	22.4	22.5	22.7	22.9
21.1	21.3	21.5	21.6	21.8	22.0	22.2	22.3	**22.5**	22.7	22.9	23.0	23.2	23.4
21.6	21.8	22.0	22.1	22.3	22.5	22.7	22.8	**23.0**	23.2	23.4	23.5	23.7	23.9
22.1	22.3	22.5	22.6	22.8	23.0	23.2	23.3	**23.5**	23.7	23.9	24.0	24.2	24.4
22.6	22.8	23.0	23.1	23.3	23.5	23.7	23.8	**24.0**	24.2	24.4	24.5	24.7	24.9
23.1	23.3	23.5	23.6	23.8	24.0	24.2	24.3	**24.5**	24.7	24.9	25.0	25.2	25.4
23.6	23.8	24.0	24.1	24.3	24.5	24.7	24.8	**25.0**	25.2	25.4	25.5	25.7	25.9
24.1	24.3	24.5	24.6	24.8	25.0	25.2	25.3	**25.5**	25.7	25.9	26.0	26.2	26.4
24.6	24.8	25.0	25.1	25.3	25.5	25.7	25.8	**26.0**	26.2	26.4	26.5	26.7	26.9
25.1	25.3	25.5	25.6	25.8	26.0	26.2	26.3	**26.5**	26.7	26.9	27.0	27.2	27.4
25.6	25.8	26.0	26.1	26.3	26.5	26.7	26.8	**27.0**	27.2	27.4	27.5	27.7	27.9
26.1	26.3	26.5	26.6	26.8	27.0	27.2	27.3	**27.5**	27.7	27.9	28.0	28.2	28.4
26.6	26.8	27.0	27.1	27.3	27.5	27.7	27.8	**28.0**	28.2	28.4	28.5	28.7	28.9
27.1	27.3	27.5	27.6	27.8	28.0	28.2	28.3	**28.5**	28.7	28.9	29.0	29.2	29.4
27.6	27.8	28.0	28.1	28.3	28.5	28.7	28.8	**29.0**	29.2	29.4	29.5	29.7	29.9
28.1	28.3	28.5	28.6	28.8	29.0	29.2	29.3	**29.5**	29.7	29.9	30.0	30.2	30.4
28.6	28.8	29.0	29.1	29.3	29.5	29.7	29.8	**30.0**	30.2	30.4	30.5	30.7	30.9
29.1	29.3	29.5	29.6	29.8	30.0	30.2	30.3	**30.5**	30.7	30.9	31.0	31.2	31.4
29.6	29.8	30.0	30.1	30.3	30.5	30.7	30.8	**31.0**	31.2	31.4	31.5	31.7	31.9
30.1	30.3	30.5	30.6	30.8	31.0	31.2	31.3	**31.5**	31.7	31.9	32.0	32.2	32.4
30.6	30.8	31.0	31.1	31.3	31.5	31.7	31.8	**32.0**	32.2	32.4	32.5	32.7	32.9
31.1	31.3	31.5	31.6	31.8	32.0	32.2	32.3	**32.5**	32.7	32.9	33.0	33.2	33.4
31.6	31.8	32.0	32.1	31.3	32.5	32.7	32.8	**33.0**	33.2	33.4	33.5	33.7	33.9
32.1	32.3	32.5	32.6	32.8	33.0	33.2	33.3	**33.5**	33.7	33.9	34 0	34.2	34.4
32.6	32.8	33.0	33.1	33.3	33.5	33.7	33.8	**34.0**	34.2	34.4	34.5	34.7	34.9
33.1	33.3	33.5	33.6	33.8	34.0	34.2	34.3	**34.5**	34.7	34.9	35.0	35.2	35.4
33.6	33.8	34.0	34.1	34.3	34.5	34.7	34.8	**35.0**	35.2	35.4	35.5	35.7	35.9

---

[a] Beilage zum Beglaubigungsschein für den Abelschen Petroleumprober: Physikalisch-Technische Reichsanstalt, 1910.

TABLE 2.—*Table for converting barometric pressures from millimeters to inches.*[a]

[700 to 779 mm.]

	0	1	2	3	4	5	6	7	8	9
70	27.559	27.598	27.638	27.677	27.716	27.756	27.795	27.835	27.874	27.913
71	27.953	27.992	28.031	28.071	28.110	28.150	28.189	28.228	28.268	28.307
72	28.346	28.386	28.425	28.465	28.504	28.543	28.583	28.622	28.661	28.701
73	28.740	28.779	28.819	28.858	28.898	28.937	28.976	29.016	29.055	29.094
74	29.134	29.173	29.213	29.252	29.291	29.331	29.370	29.409	29.449	29.488
75	29.528	29.567	29.606	29.646	29.685	29.724	29.764	29.803	29.842	29.882
76	29.921	29.961	30.000	30.039	30.079	30.118	30.157	30.197	30.236	30.276
77	30.315	30.354	30.394	30.433	30.472	30.512	30.551	30.590	30.630	30.669

[a] Whole numbers, millimeters; decimal numbers, inches.

SPECIFICATIONS FOR THE BUREAU OF MINES FLASH TESTERS.

In order to meet the demand for a more accurate tester in the industry and in order that there may be no question as to the exact dimensions of the testers and the details of their construction, as modified by the Bureau of Mines, specifications for their construction are presented herewith.

1. These specifications are intended to provide a flash-testing apparatus for light oil and a flash-testing apparatus for heavy oil.

2. Drawings [a] (C–317, C–318, C–319, B–128, B–129, and A–4) and Pls. I and II accompany these specifications, and both drawings and specifications shall be considered each as supplementary to the other, so that the material and workmanship shown, called for, or implied by one and not the other shall be worked into place as though specified in both.

Should any figure be omitted from the general plan or from the details, or should any error appear in either, the contractor shall apprise the Bureau of Mines of such omission or error, and shall under no circumstances proceed with the work without further detailed drawings or instructions.

No deviation from the approved drawings and these specifications will be allowed, unless written permission shall have been previously granted by the Bureau of Mines.

On the drawings, figures shall always have preference over the scale in dimensions.

3. All joints, except those not subject to the heat of the apparatus, shall be pinned, riveted, screwed, or brazed. Those not affected by heat may be soldered. Where dimensions have been intentionally omitted, the contractor is empowered to use his best judgment in the construction and assembling of the parts affected.

All pins, screws, etc., now shown on the drawings shall be supplied and assembled where required. A clock spring shall be provided for part 15–C–318 and C–319. The cover and details thereon of part 1–C–318 are of similar construction for both type B–128 and type B–129 flash testers.

The contractor is empowered to use material and tools of standard dimensions where the use of same will not interfere with the operation or workmanship of the apparatus, the dimensions on the drawings being converted from the nearest metric dimension on the apparatus from which this design was made.

Both types of apparatus shall be assembled and tested before delivery to the Bureau of Mines.

4. The prices given in the accepted proposal shall include the supply and erection in a good, sound, substantial, and workmanlike manner of all the parts required for the completion of the apparatus and shall include all the parts shown on the drawings and described in these specifications.

No deviation from the price as specified in the accepted proposal shall be allowed except in accordance with the section of these specifications relative to changes in section 5.

5. The right is reserved to make such changes in the order, plans, and specifications as may be deemed necessary or advisable by the undersigned, or other duly accredited, representative of the Bureau of Mines. The effect upon the cost of the work as caused by such changes shall be ascertained by the aforesaid representative, and the contractor shall agree and consent that the stipulated price, increased or decreased by the sum ascertained, shall be accepted in full satisfaction for the work

---

[a] The drawings will be furnished any instrument maker or interested person on request.

done, provided that any changes determined upon shall be stipulated upon and agreed to in writing by the parties to the contract.

6. All work shall be subject to the inspection of a duly accredited representative of the Bureau of Mines at any time during its construction and after its completion and will not be accepted if, in his judgment, it does not fulfill the intent and purpose herein stated.

The thermometer shall be calibrated when immersed to the collar and under conditions that correspond as nearly as possible to the conditions of testing.

There shall be two lines engraved on the outside of the glass body at the extremities of the scale range to show that the scale has not changed or slipped.

Thermometers Nos. 2 and 3 (drawing sheet A–4) are to be graduated in half degrees.

Thermometers Nos. 1, 4, and 5 (drawing sheet A–4) are to be graduated in whole degrees.

A special clockworks for operating the shutter may be substituted for the clockworks shown in drawing C–318, or the clockworks may be in accord with any standard movement that will perform the same operation in an equal period of time. The clockworks for operating the shutter shall consist of one standard alarm barrel with special arbor, one standard lantern pinion with escape wheel, one special hammer and hammer staff to govern speed of movement, which should be such that the cover will be opened and the test flame exposed for a period of 1 second.

These parts are to be mounted in a frame 15 mm. in diameter, made of 0.5-mm. brass stock held together by three special pillars approximately 10 mm. high.

The complete set of testers shall consist of three cups (1–C–317), one cover with clockworks complete for operating shutter, one bath as shown in 1–B–128, and one bath as shown in 1–B–129, complete with a gas burner for each bath and a set of five thermometers.

The overflow hole of the oil cup shall be on the side opposite the filling point.

BIBLIOGRAPHY.

Herewith is presented a bibliographic list of articles and books cited in the text of this report. The references are numbered according to the order in which they appear in the text.

1. Allen, I. C., The preparation of specifications for petroleum products. Technical Paper 36, Bureau of Mines, 1913, p. 9.

2. Aisinmann, S., Die gesetzliche Normirung des Testpunktes von Petroleum. Chem. Ztg., vol. 20, May 16, 1896, p. 396.

3. Pick, P., Ueber die Zwechmässigkeit der Bestimmung des Flamm- und Brennpunktes bei Schmierölen. Chem. Ztg., Rep., vol. 33, Mar. 18, 1909, p. 162; Oest. Poly. Ztschr., 1909, pp. 10–11.

6. Chemische Zeitung., Zur petroleumfrage in England. Vol. 20, Mar. 2, 1896, p. 361.

7. Mickolls, A. H., A method for the classification of the hazardous properties of certain liquids. Quarterly of the National Fire Protection Association of the United States, vol. 1, April, 1908, p. 68.

8. Robinson, J. A., Denatured alcohol. Quarterly of the National Fire Protection Association of the United States, vol. 1, 1908, p. 92.

9. National Board of Fire Underwriters. List of gas, oil, mechanical, and chemical appliances. Special Bulletin, January, 1913.

10. Wiebe, H. F., Zur internationalen Vereinheitlichung der Flammpunktsbestimmungen. Petroleum, vol. 7, Jan. 17, 1912, p. 406.

11. Syme, W. A., Oil Bulletin, North Carolina Department of Agriculture, No. 1, vol. 31, Jan., 1910, p. 11.

12. Abel, F. A., The flashing test for petroleum. Jour. Soc. Chem. Ind., vol. 1, 1862, pp. 471–478.

13. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, pp. 545–596.

14. Board of Trade, Standards Office, Petroleum Act 1879 (42 and 43 Vict., c. 47).

15. Steuart, D. R., The standard for flash point for mineral oils. Jour. Soc. Chem. Ind., vol. 15, May 30, 1896, pp. 335–336.

16. Chamberlin, C. D., On uniform oil inspection. Views of the National Petroleum Association to State delegates in conference on uniform legislation, under the auspices of the National Civic Federation, Washington, D. C., January, 1910, p. 1.

17. Redwood, Boverton, The Tagliabue open flash-point tester. Petroleum and its products, vol. 2, 1906, p. 546.

18. Redwood, Boverton, The Tagliabue closed flash-point tester. Petroleum and its products, vol. 2, 1906, p. 576.

19. Redwood, Boverton, The Elliot flash-point tester. Petroleum and its products, vol. 2, 1906, p. 577.

20. Redwood, Boverton, The Foster flash-point tester. Petroleum and its products, vol. 2, 1906, p. 581.

21. Abel, F. A., Der Abel Entzündungsapparat. Neue Wochenschr. Oel. Fettw., 1879, p. 105; Ztschr. Chem. Grossgew, vol. 4, p. 63; Ztschr. anal. Chem., 1881, p. 17; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 558–571; Holde, D., Untersuchung der Mineralöle und Fette, 1909, p. 52.

22. Redwood, Boverton, Pensky-Martens flash-point tester for lubricating oils; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 593; Holde, D., Untersuchung der Mineralöle und Fette, 1909, p. 133; Benedikt-Ulzer, Analyse der Fette und Wachsarten, 1908, p. 386.

23. Syme, W. A., Oil Bulletin, North Carolina department of agriculture, No. 1, vol. 31, January, 1910, p. 11.

24. Journal du Pétrole, Flammpunktsprüfung für Brennöle, vol. 10, 1910, p. 101; Chem. Rev. Fett. Harz. Ind., vol. 17, June, 1910, p. 141.

25. Journal du Pétrole, Les épreuves d'inflammabilité du lampant, vol. 11, Apr. 15–20, 1911, p. 101.

26. Journal du Pétrole, Les épreuves d'inflammabilité des huiles minérales, vol. 12, 1912, p. 10.

27. Aisinmann, S., Ueber die Flammpunktsbestimmung der Mineralschmieröle., Dinglers Polyt. Jour., vol. 294, p. 68.

28. Allen, J., Die Bestimmung der Feuergefährlichkeit des Petroleums, Deut. Ind. Ztg., 1868, p. 437; Wagner's Jahresb., 1868, p. 729.

29. Redwood, Boverton, The Arnaboldi flash-point tester. Petroleum and its products, vol. 2, 1906, p. 548.

30. Attfield, J., On the igniting point of petroleum. Pharm. Jour., ser. 2, vol. 8, 1867, pp. 318–325; ser. 3, vol. 2, 1871, p. 43; Chem. News, vol. 14, 1866, pp. 257–258; Wagner's Jahresb., 1867, p. 725.

31. Chandler, C. F., Tagliabue's open flash tester. Report on petroleum, 1871, p. 36.

32. Chandler, C. F., The closed flash-point tester of Tagliabue, the pyrometer. Report on petroleum, 1871, p. 36; Hannover Monatschr. von Skalweit, 1879, p. 95; Bolleys Handbuch Technische Chemische Untersuchungen, 4th ed., p. 607; 5th ed., p. 667; Ztschr. anal. Chem., 1881, p. 8.

33. Zeitschrift der analytische Chemie. Petroleum Entzündungsprüfer, 1881, p. 11; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 549.

34. Redwood, Boverton, The Ehrenberg flash-point tester. Petroleum and its products, vol. 2, 1906, p. 582.

35. Engler, C., Die Prüfung des Petroleums auf seine Feuergefährlichkeit. Ztschr anal. Chem., vol. 20, 1881, pp. 1–36.

36. Engler, C., and Haass, R., Die Prüfung des Petroleums auf seine Feuergefährlichkeit. Wagner's Jahresb., 1881, pp. 1199–1200.

37. Engler, H., Ueber die Bestimmung der Fuergefahrlichkeit des Petroleums, Ber. Deut. Chem. Gesell., vol. 12, 1879, p. 2184.

38. Ernecke and Hannemann, Die Bestimmung der Feuergefährlichkeit des Petroleums. Deut. Ind. Ztg., 1870, p. 19; Wagner's Jahresb., 1870, pp. 707, 709.

39. Granier, E., Appareil pour constater le degré d'inflammabilité des huiles de pétrole destinées à l'éclairage. Bull. Soc. Encour. Ind. Nat., vol. 72, 1872, p. 196.

40. Höfer, H., A flash tester for petroleums. Centennial Exposition, Phila., Petroleum Industry of North America, 1876, p. 143.

41. Hutton, Die Bestimmung der Feuergefährlichkeit des Petroleums. Dinglers Polyt. Jour., vol. 192, p. 261.

42. Redwood, Boverton, The Indiana State flash-point tester. Petroleum and its products, vol. 2, 1906, p. 548.

43. Jacobsen, E., Der Entflammungsprőber von Abeljanz. Chem. Ind., vol. 4, Aug., 1881, p. 272; Deut. Ind. Ztg., 1881, p. 79.

44. Kyll, Die Bestimmung der Feuergefährlichkeit des Petroleums. Hannover Monatsschr. Skalweit, 1879, p. 92; Leybold's Preisverz, No. 1572, 1880.

45. Lenoir and Forster, Die Bestimmung der Fuergefährlichkeit des Petroleums. Chem. Ztg., 1879, p. 205.

46. Redwood, Boverton, The Minnesota State flash-point tester. Petroleum and its products, vol. 2, 1906, p. 549.

47. Möser, Die Bestimmung der Feuergefährlichkeit des Petroleums.

48. Redwood, Boverton, The Saybolt flash-point tester. Petroleum and its products, vol. 2, 1906, p. 548.

49. Redwood, B., The Squires flash-point tester. Petroleum and its products, vol. 2, 1906, p. 547.

50. Vette, R., Petroleumprüfer. Chem. Centralbl., vol. 12, Dec. 21, 1881, p. 812; Ind. Blat., vol. 18, Oct. 15, 1881, p. 322.

51. Warren, H. N., A simple electrical apparatus for determining the flashing point of mineral oils. Chem. News, vol. 62, 1890, p. 311.

52. Weise, V., Die Bestimmung der Feuergefährlichkeit des Petroleums. Polyt. Centralbl., 1871, p. 378; Chem. Centralbl., 1871, p. 327; Deut. Ind. Ztg., 1871, p. 163; Wagner's Jahresb., 1871, p. 863.

53. Courtois, F. A., Flash tester. U. S. patent, Apr. 25, 1905, No. 788250; Jour. Soc. Chem. Ind., vol. 24, Sept. 30, 1905, p. 987; Ztschr. angew. Chem., 1905, p. 847.

54. Kissling, R., Determination of the flashing and ignition points of lubricating oils. Chem. Ztg., 1899, pp. 800–801; Jour. Soc. Chem. Ind., vol. 18, 1899, p. 1114.

55. Künkler, A., Ueber flamm- und Brennpunktsbestimmungen von Mineralschmierölen. Chem. Ztschr., vol. 23, 1899, pp. 166–169.

56. Marcusson, J., Bestimmung des Flamm- und Brennpunktes von Schmierölen im offenen Tiegel. Chem. Ztg., vol. 30, 1906, p. 1183; Chem. Rev. Fett. Harz. Ind., vol. 14, 1907, pp. 11, 54.

57. Marcusson, J., Flammpunktsbestimmung für Schmiermittel mittels die ofene Methode. Chem. Rev. Fett. Harz. Ind., vol. 14, 1907, pp. 9–10; Chem. Abs., June 5, 1907, p. 1478.

58. Stoeber, E., Der Flammpunkt als Hilfsmittel bei Wachsanalysen. Chem. Ztg., vol. 33, 1909, p. 1275; Chem. Rev. Fett. Harz. Ind., vol. 17, January, 1910, p. 16.

59. Redwood, Boverton, The Truemann flash-point tester. Petroleum and its products, vol. 2, 1906, p. 595.

60. Walker, P. H., An apparatus to determine the flash point of lubricants. Bureau of Chem. Bull. 109, U. S. Dept. of Agri., 1910, p. 11.

61. Herbig, W., Zur Bestimmung des Flammpunktes der Mineralöle. Chem. Rev. Fett. Harz. Ind., vol. 12, 1905, pp. 26–30; Jour. Soc. Chem. Ind., vol. 24, Feb. 28, 1905, p. 212.

62. Braun, O., Flash-point tester. Sitz. Ver. Beförd. Gewerbfl. Preuss., 1881, p. 212; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 582.

63. Chandler, C. F., Tagliabue geschlossener Petroleum-prüfungsapparat (Pyrometer). Hannover Monatschr. von Skalweit, 1879, p. 95; Bolley and Kopp, Handbuch des technische chemische Untersuchungen, 4th ed., p. 607; 5th ed., p. 667; Ztschr. anal. Chem., 1881, p. 15.

64. Engler, C., Ein Apparat zur Prüfung des Petroleums. Chem. Ind., vol. 3, 1880, pp. 53–56; Chem. Ztg., vol. 4, Nov. 18, 1880, p. 767.

65. Engler, C., Verbesserte Entzündungsprüfer "Naphtometer." Correspondenzbl. Ver. Analyt. Chemiker, 1880, p. 129; Chem. Ind., vol. 3, Nov., 1880, p. 389.

66. Heumann., Flammpunktpröber Chem. Ind., vol. 7, 1884, p. 188; Posts Chemtech. Anal., 11, 1888, p. 301; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 575.

67. Kuckla, Geschlossene Entzündungsprüfer. Wagner's Jahresb., 1866, p. 673.

68. Redwood, Boverton, The Luchaire flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 580.

69. Redwood, Boverton, The Mann flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

70. Redwood, Boverton, The Millspaugh flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

71. Parish, Edward, On a new apparatus for testing coal oils. Trans. Am. Pharm. Ass., 1862, pp. 206–209; Wagner's Jahresb., vol. 10, 1864, p. 675; vol. 11, 1865, p. 749; vol. 12, 1866, p. 671; Ztschr. anal. Chem., vol. 3, 1864, p. 228; vol. 20, 1881, p. 21, Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 580.

72. Redwood, Boverton, The Phlog-elaio-metre flash-point tester. Petroleum and its products, vol. 2, 1906, p. 581.

73. Skalweit, J., Neue Apparat für Bestimmung des Entflammbarkeites. Ztschr. anal. Chem., 1881, p. 305.

74. Redwood, Boverton, The Wisconsin flash-point tester. Petroleum and its products, vol. 2, 1906, p. 577.

75. Petroleum World. Closed-cup flash tests; description and method of using an apparatus. Vol. 9, February, 1912, p. 79.

76. Steuart, D. R., Flash point of burning oils. Chem. News, June 3, 1893; Jour. Soc. Chem. Ind., vol. 15, 1896, pp. 173–179; Jour. Ind. Eng. Chem., vol. 1, September, 1909, p. 679.

77. Bernstein, A., Apparat zur Prüfung Entzündbarkeit des Petroleums. Wagner's Jahresb., vol. 25, 1879, p. 1180; Deut. Ind. Ztg., 1879, p. 517; Ztschr. Anal; Chem., 1881, p. 24; Sitzŭng Verein Bëforderŭng Gewerbfleiss, Preuss, 1879, p. 173. Dinglers polyt. Jour. 1881, p. 136; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 582.

78. Braun, O., Verbesserung an dem Abelischen Petroleumprober. Rep. Anal. Chem., vol. 3, Feb. 1, 1883. Chem. Ztg., 1882, p. 1301, German patent 19757; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 572.

79. Engler, C., Erwiderung an A. Bernstein's Entzündungsprüfer. Chem. Ind., vol. 3, April, 1880, p. 156.

80. Engler, C., Ein Apparat zur Prüfung des Petroleums. Chem. Ind., vol. 3, February, 1880, p. 53. Ztschr. anal. Chem., vol. 20, 1881, p. 27; Elktrische Flammpunktprober, Posts Chem.-tech. Anal., vol. 2, 1888, p. 299; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 573.

81. Redwood, Boverton, The Gawalowski flash-point tester. Petroleum and its products, vol. 2, 1906, p. 585.

82. Granier, E., Geschlossene Entzündungsprüfer. Polyt. Centralbl., 1873, p. 1029; Compt. Rend. Soc. Encon. vol. 15, 1872; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 579.

83. Gray, J., Apparatus for determining the flash points of heavy mineral oils. Jour. Soc. Chem. Ind., vol. 10, Apr. 30, 1891, p. 348; Jour. Chem. Soc., vol. 62, 1892, p. 542; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 595.

84. Harker, J. A., and Higgins, W. F., On the methods and apparatus used in petroleum testing. Collected Researches, Nat. Phys. Lab., vol. 8, 1911, p. 19; Petroleum World, July, August, September, 1911; Petroleum, vol. 7, Jan. 3, 1912, p. 350.

85. Holde, D., Die Flammpunktsprüfung von Mineralschmierölen. Mitth. k. techn. Versuchsanst, vol. 7, 1889, pp. 64–72; Jour. Soc. Chem. Ind., vol. 8, Sept. 30, 1889, p. 734.

86. Holde, D., An electrically heated Pensky flash tester. Petroleum, vol. 4, 1908, p. 14; Chem. Ztg., vol. 32, 1908, p. 650; Chem. Abs., vol. 3, 1909, p. 707.

87. Jacobsen, E., Der "Taucher" Entflammungsprőber von O. Braun. Chem. Ind., vol. 4, July, 1881, p. 229. German patent 14022, Aug. 31, 1880.

88. Redwood, B., The Keates flash-point tester. Petroleum and its products, vol. 2, 1906, p. 550.

89. Künkler, Die Truemann Flammpunktpröber für Schmiermittel. Die Maschinenschmierung, 1894; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 595.

90. Letheby, Flash-point tester. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 573.

91. Redwood, B., The Pease flash-point tester. Petroleum and its products, vol. 2, 1906, p. 573.

92. Saybolt, G., Die Bestimmung der Feuergefährlichkeit des Petroleums. Chem. Ind., 1880, p. 55; Ztschr. Chem. Grossgew, 1879, p. 63.

93. Saybolt, G., Electrisch Entzündungsprüfer. Chem. Ind., 1880, p. 55; Ztschr. Chem. Grossgew, 1879, p. 63; Ztschr. Chem., 1881, p. 13.

94. Schmitz, Ruhrvorrichtung; für den Martens-Pensky-Apparat. Chem. Ztg., vol. 33, 1909, pp. 1107, 1221, 1304; Chem. Abs., vol. 4, Jan. 20, 1910, p. 131; Chem. Rev. Fett. Harz. Ind., vol. 16, November, 1909, p. 281.

95. Sintenis, Petroleum "Pyrometer" oder Entflammbarbeitsapparat. Hannover Monatschr. von Skalweit, 1879, p. 96; Chem. Ztg., 1879, p. 254; Ztschr. anal. Chem., 20, 1881, pp. 20, 21.

96. Vette, Flash-point tester. Dinglers Polyt. Jour., 1862, p. 476; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

97. Weber, R., Petroleumprüfüng auf seine Entzündlichkeit. Ind. Blätter, 1878, p. 12; Wagner's Ber., 1877, p. 1033; Deut. Ind. Ztg., 1878, p. 6.

98. Wiebe, H. F., Obere Brauchbarkeitsgrenze des Abel-Penskyschen Apparates und seine Vergleichung mit dem Penskyschen Flammpunktprüfer. Petroleum, vol. 8, Oct. 2, 1912, p. 16.

99. Wiebe, H. F., The upper limit of usability of the Abel-Pensky apparatus and its comparison with the Pensky flash-point tester. Proceedings 8th Inter. Cong. App. Chem., vol. 10, p. 303–307. Chem. Abs., vol. 6, Nov. 10, 1912, p. 3178.

100. Wiebe, H. F., and Hebe, P., Comparison of English and German flash testers. Petroleum, vol. 5, 1910, p. 885. Chem. Abs., vol. 4, Sept. 10, 1910, p. 2370.

101. Beilstein, F. F., Ueber Petroleumprüfung. Ztschr. anal. Chem., vol. 22, 1883, pp. 309–316; vol. 23, 1883, p. 312; Wagner's Jahresb., 2, 1885, p. 2177; Chem. Centralbl., 1885, p. 286; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

102. Liebermann, L., Eine neue Methode zur Bestimmung des Entflammungspunktes von Petroleum. Ztschr. anal. Chem., vol. 21, 1882, p. 321–329; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 584.

103. Reythien, A., and Hempel, H., Die Bestimmung des Entflammungspunktes von Flüssigkeiten. Farben Ztg., vol. 13, 1907; Chem. Rev. Fett. Harz. Ind., pt. 3, 1908, pp. 57–60.

104. Stoddard, J. T., On the determination of the flashing point of petroleum. Am. Chem. Jour., vol. 4, 1882, pp. 285–288, 293–295; vol. 5, 1883, pp. 459–460; vol. 6, 1884, pp. 18–23; Jour. Chem. Soc., vol. 46, 1884, p. 1431.

105. Stoddard, J. T., Determination of flash point of petroleum. Jour. Am. Chem. Soc., vol. 5, 1883, p. 517; Ber., Deut. chem. Gesell., vol. 15, 1882, p. 2555; Jour. Chem. Soc., vol. 44, 1883, p. 383; Chem. News, 1882, p. 297.

106. Haass, R., Zur Prüfung des Petroleums auf seine Feuergefährlichkeit. Chem. Ind., vol. 3, 1880, pp. 123–126.

107. Haass, R., Zur Prüfung des Petroleums auf seine Feuergefährlichkeit. Chem. Ind., Apr. 3, 1880, p. 123; Ztschr. anal. Chem., 1881, p. 29; Ztschr. anal. Chem., vol. 20, 1880, p. 29; Petroleum and its products, vol. 2, 1906, p. 575.

108. Hörler, H., Die Entflammungstemperatur des Petroleums in Rücksicht auf Form and Grösse des Gefässe. Dinglers Polyt. Jour., vol. 234, p. 52; Chem. Ind., vol. 2, p. 431; Wagner's Jahresb., 1879, p. 1175; Ztschr. anal. Chem., 1881, p. 28.

109. Meyer, V., Die Bestimmung des Entflammungspunktes des Petroleums. Wagner's Jahresb., 1879, p. 1175; Fittica Jahresb., 1879, p. 1145; Ztschr. anal. Chem., 1881, p. 28.

110. Meyer, V., Gutachten betreffend eine Verordnung über den Verkehr mit Petroleum u. s. w. feuergefährliche Flüssigkeiten erstättet. Chem. Ind., vol. 2, Oct. 1879, p. 352; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 575.

111. Charitschkoff, K. W., Der Zusammenhang zwischen Entflammungstemperatur und der Dampftension brennbarer Flüssigkeiten mit niedriger Siedetemperatur derselben. Chem. Ztg., vol. 32, Apr. 11, 1908, p. 382; Russ. Phys. Chem. Soc. St. Petersburg, vol. 1, Nov. 14, 1907.

112. Bolley and Kopp, Die Geissler Methode der Bestimmung der Feuergefährlichkeit des Petroleums, mittels "Vaporimeter." Handbuch des technische chemische Untersuchungen, 5th ed., p. 740.

113. Meusel, Die Bestimmung der Feuergeführlichkeit des Petroleums. Polyt. Centralbl., 1872, p. 310; Deut. Ind. Ztg., 1872, p. 155; Chem. Centralbl., 1872, p. 234; Wagner's Jahresb., 1872, p. 847.

114. Salleron, J., and Urbain, V., Apparat für die Bestimmung des Entflammbarkeit des Petroleums. Ztschr. anal. Chem., vol. 5, 1881, p. 247; Dinglers Polyt. Jour., vol. 181, p. 397, vol. 232, p. 354; Deut. Ind. Ztg., 1866, p. 164; Wagner's Jahresb., 1866, p. 671; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 585; Ann. gen. Civil, 5, 1866, p. 154.

115. Salleron, J., and Urbain, V., Nouvelle méthode d'essai des huiles minérales. Compt. Rend. vol. 62, 1886, p. 43.

116. Vanderweyde, P. H., Improved fire test of illuminating petroleum, without the use of fire. Amer. Gaslight Jour., vol. 15, 1871, pp. 119, 120, 133; Jour. Chem. Soc., vol. 10, 1872, p. 272; Sci. Am., 1871, p. 162; Dinglers Polyt. Jour., vol. 202, p. 301; Ztschr. anal. Chem., vol. 2, p. 338; Polyt. Centralbl., 1872, p. 138; Deut. Ind. Ztg., 1871, p. 478; Wagner's Jahresb., 1871, p. 862.

117. Barran, d'A. de, Sur le procès Granier pour diminuer le point d'inflammation des pétroles. Compt. Rend., vol. 73, 1871, p. 490.

118. Beilstein, F. P., Die Prüfung des Petroleums. Chem. Centralbl., 1885, p. 286.

119. Rosenbladt, T., Bestimmung der Entflammungstemperatur des Petroleums. Chem. Ztg., vol. 10, 1886, p. 1587; Jour. Soc. Chem. Ind., vol. 6, Apr. 29, 1887, p. 304; Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 587.

120. Dvorkovitz, P., Relation of flashing points to the boiling points of (petroleum) illuminating oils. Petrol. Rev., vol. 13, 1905, pp. 7–8, 24–25; Jour. Soc. Chem. Ind., vol. 24, Aug. 15, 1905, p. 838.

121. Schottky, A., Tagliabue's offener Entzündungsprüfer. Chem. Ztg., vol. 3, Apr. 17, 1879, p. 193, Apr. 24, p. 205.

122. Martens, A., Ueber die Flammpunktsbestimmungen von Schmierölen. Mitteilungen k. Versuchsanstalt, vol. 11, 1893, p. 37–45; Jour. Soc. Chem. Ind., vol. 12, Nov. 30, 1893, p. 936.

123. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 557.

124. Redwood, Boverton, Petroleum and its products, vol. 2, 1906, p. 559.

125. Abel, F. A., Entflammungspunkt des Petroleums. Wagner's Jahresb., 1883, p. 1600.

126. Steuart, D. R., The Abel test and the standard of safety for mineral oil. Chem. News, vol. 70, 1894, p. 284, 285.

127. Holde, D., Die Berücksichtigung der Ausdehnung der Oele bei der Flammpunktbestimmung von hochsiedenden Mineralölen. Ztschr. angew. Chem., 1897, pp. 51–52; Jour. Soc. Chem. Ind., vol. 5, 1897, p. 322.

128. Martens, A., Die Flammpunktsprüfung von Mineralschmierölen. Polyt. Jour., vol. 295, 1895, p. 189.

129. Calvert, F. C., On the testing of petroleum spirit. Chem. News, vol. 21, Feb. 25, 1870, p. 85.

130. Mayer, F., Thermometerkorrekturen bei der Bestimmung des Flamm-und Brennpunktes von Oelen. Ztschr. angew. Chem., vol. 23, p. 55; Chem. Rev. Fett. Harz. Ind., vol. 17, pt. 3, March, 1910, p. 59; Petroleum, vol. 5, Feb. 16, 1910, p. 577; Chem. Abs., vol. 4, May 20, 1910, p. 1367.

131. Jenkins, J. H. B., The Abel flash-point test. Chem. News, 71, 1895, pp. 106–107.

132. Abel, F. A., and Redwood, Boverton, Note on the employment of the Abel petroleum-testing apparatus in tropical climates. Chem. News, May 2, 1884; Jour. Soc. Chem. Ind., vol. 3, May 29, 1884, p. 318.

133. Abel, F. A., and Redwood, Boverton, Petroleum testing in tropical climates with Abel's apparatus. Chem. News, vol. 49, 1884, p. 196.

134. Paul, B. H., The mode of testing mineral oils used for lamps. Chem. News, vol. 21, Jan. 7, 1870, p. 2.

135. Zaloziecki, R., Über die Feuergefährlichkeit des Petrols. Chem. Centralbl., vol. 68, pt. 1, 1897, pp. 212–213; Milch. Ztg., 20, p. 821, pp. 837–839.

136. Peltzer, R., Ueber die Entflammbarkeit des Petroleums und des Schieferöles. Dinglers Polyt. Jour., vol. 189, 1868, p. 61–63; Jour. Franklin Inst., vol. 86, 1868, pp. 333–336.

137. Sherman, H. C., Gray, T. T., and Hammerschlag, H. A., Comparison of the calculated and determined viscosities and flashing and burning points of oil mixtures. Jour. Ind. Eng. Chem., vol. 1, 1909, p. 13; Chem. Abs., May 10, 1909, p. 1079.

138. Charitschkow, K., The influence of water upon the flashing point and viscosity of mineral lubricating oils and naphtha residues. Vestnik zhirov. prom., vol. 8, 1907, p. 60; Chem. Ztg., vol. 31, 1907, p. 376; Chem. Rev. Fett. Harz. Ind., vol. 14, p. 225; Chem. Ztg., Rep. 1907; Chem. Abs., vol. 2, Jan. 10, 1908, p. 176; Feb. 10, p. 456; Jour. Soc. Chem. Ind., vol. 26, Sept. 16, 1907, p. 958.

139. Sadtler, S. S., Influence of water upon the flashing point and viscosity of mineral lubricating oils and naphtha residues. Chem. Abs., vol. 2, pt. 1, 1908, p. 176.

140. Matuschek, J., The influence of the water present on the flash point and combustion point of petroleum. Oesterr. Chem. Zeit., vol. 4, 1901, p. 200; Chem. News, vol. 85, 1902, p. 267; Jour. Soc. Chem. Ind., vol. 21, July 15, 1902, p. 909.

141. Allen, I. C., and Jacobs, W. A., Methods for the determination of water in petroleum and its products. Technical Paper 25, Bureau of Mines, 1912, p. 8.

142. Journal of the Society of Chemical Industry. Testing flashing point of petroleum. Vol. 3, Jan. 29, 1884, p. 8.

143. Kissling, R., Die Prüfung sogenannte hochtestiger Leuchtöle (Sicherheitsöle auf ihre Entflammbarkeit. Chem. Zeit., vol. 16, 1892, p. 1070; Jour. Soc. Chem. Ind., vol. 12, May 31, 1893, p. 467.

144. Allen, I. C., Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas. Technical Paper 3, Bureau of Mines, 1911, pp. 7–11.

PUBLICATIONS ON PETROLEUM TECHNOLOGY.

A limited supply of the following Bureau of Mines publications is avaliable for free distribution. Requests for publications should be addressed to the Director, Bureau of Mines, Washington, D. C.:

BULLETIN 19. Physical and chemical properties of the petroleums of the San Joaquin Valley, Cal., by I. C. Allen and W. A. Jacobs, with a chapter on analyses of natural gas from the southern California oil fields, by G. A. Burrell. 1911. 60 pp., 2 pls., 10 figs.

BULLETIN 65. Oil and gas wells through workable coal beds; papers and discussions, by G. S. Rice, O. P. Hood, and others. 1913. 101 pp., 1 pl., 11 figs.

TECHNICAL PAPER 3. Specifications for the purchase of fuel oil for the Government, with directions for sampling oil and natural gas, by I. C. Allen. 1911. 13 pp.

TECHNICAL PAPER 10. Liquefied products from natural gas; their properties and uses, by I. C. Allen and G. A. Burrell. 1912. 23 pp.

TECHNICAL PAPER 25. Methods for the determination of water in petroleum and its products, by I. C. Allen and W. A. Jacobs. 1912. 13 pp., 2 figs.

TECHNICAL PAPER 26. Methods of determining the sulphur content of fuels, especially petroleum products, by I. C. Allen and I. W. Robertson. 1912. 13 pp., 1 fig.

TECHNICAL PAPER 32. The cementing process of excluding water from oil wells, as practiced in California, by Ralph Arnold and V. R. Garfias. 1913. 12 pp., 1 fig.

TECHNICAL PAPER 36. The preparation of specifications for petroleum products, by I. C. Allen. 1913. 12 pp.

TECHNICAL PAPER 37. Heavy oil as fuel for internal-combustion engines, by I. C. Allen. 1913. 36 pp.

TECHNICAL PAPER 38. Wastes in the production and utilization of natural gas and means for their prevention, by Ralph Arnold and F. G. Clapp. 1913. 29 pp.

TECHNICAL PAPER 42. The prevention of waste of oil and gas from flowing wells in California, with a discussion of special methods used by J. A. Pollard, by Ralph Arnold and V. R. Garfias. 1913. 15 pp., 2 pls., 4 figs.

TECHNICAL PAPER 51. Possible causes of the decline of oil wells and suggested methods of prolonging yield, by L. G. Huntley. 1913. 32 pp., 9 figs.

TECHNICAL PAPER 57. A preliminary report on the utilization of petroleum and natural gas in Wyoming, by W. R. Calvert, with a discussion of the suitability of natural gas for making gasoline, by G. A. Burrell. 1913. 21 pp.

TECHNICAL PAPER 66. Mud-laden fluid applied to well drilling, by J. A. Pollard and A. G. Heggem. 1914. 21 pp., 12 figs.

TECHNICAL PAPER 68. Drilling wells in Oklahoma by the mud-laden fluid method, by A. G. Heggem and J. A. Pollard. 1914. 27 pp., 5 figs.

TECHNICAL PAPER 70. Methods of oil recovery in California, by Ralph Arnold and V. R. Garfias. 1913. 56 pp., 7 figs.

TECHNICAL PAPER 72. Problems of the petroleum industry; results of conferences at Pittsburgh, Pa., August 1 and September 10, 1913, by I. C. Allen. 1913. 20 pp.

○